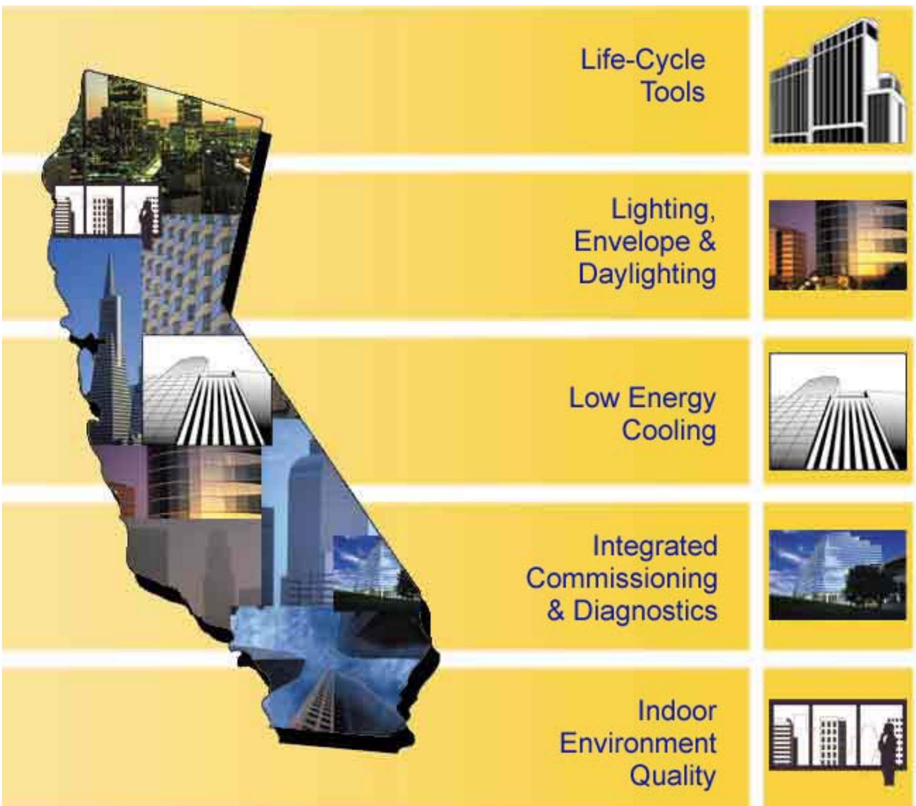
CALIFORNIA ENERGY COMMISSION

Commissioning Persistence



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Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Program's final report and its attachments are intended to provide a complete record of the objectives, methods, findings and accomplishments of the High Performance Commercial Building Systems (HPCBS) Program. This Commercial Building Energy Benchmarking attachment provides supplemental information to the final report (Commission publication # 500-03-097-A2). The reports, and particularly the attachments, are highly applicable to architects, designers, contractors, building owners and operators, manufacturers, researchers, and the energy efficiency community.

This document is the eighteenth of 22 technical attachments to the final report, and consists of research reports:

- Report on persistence of Benefits from New Building Commissioning Strategies for Improving the Persistence of Building Performance (E5P2.2T5b)
- Report on Strategies for Improving Persistence of Commissioning Benefits (E5P2.2T5c)
- Persistence of Savings Obtained from Continuous Commissioning SM (E5P2.2T5a2)
- Is Commissioning Once Enough? (E5P2.2T5b3)

The Buildings Program Area within the Public Interest Energy Research (PIER) Program produced this document as part of a multi-project programmatic contract (#400-99-012). The Buildings Program includes new and existing buildings in both the residential and the nonresidential sectors. The program seeks to decrease building energy use through research that will develop or improve energy-efficient technologies, strategies, tools, and building performance evaluation methods.

For the final report, other attachments or reports produced within this contract, or to obtain more information on the PIER Program, please visit http://www.energy.ca.gov/pier/buildings or contact the Commission's Publications Unit at 916-654-5200. The reports and attachments are also available at the HPCBS website: http://buildings.lbl.gov/hpcbs/.

Abstracts

Persistence of Benefits from New Building Commissioning

The commissioning process is gaining increasing recognition as a cost-effective strategy for reducing commercial building energy use. Although the success and cost-effectiveness of commissioning activities depend on how well the benefits of commissioning persist over time, this aspect of commissioning is not well understood.

The persistence of the benefits of commissioning new construction was recently studied as a part of the California Energy Commission Public Interest Energy Research program. Ten buildings that were commissioned as new buildings at least two years ago were evaluated. The commissioning reports, control algorithms, EMCS point measurements, and energy use data were examined to determine the persistence of selected items that were fixed during commissioning. Operator, owner, and commissioning provider interviews were conducted to help determine reasons for persistence and methods of improving persistence.

The majority of the commissioning fixes that were studied persisted. The items that did not persist were typically changes in occupancy scheduling and cooling plant control strategies. The persistence of commissioning benefits was found to be highly dependent on the working environment for building engineers and maintenance staff. Through this investigation, we identified three main reasons that benefits of commissioning did not persist: limited operator support and high operator turnover rates, poor information transfer from the commissioning process, and a lack of systems put in place to help operators track performance. Four methods for improving persistence are proposed, focusing on operator training and system documentation.

Strategies for Improving Persistence of Commissioning Benefits

More and more building owners are turning to commissioning as a quality assurance strategy. Commissioning ensures that a new building works right from day one, and gets existing buildings back on track. Although at the end of the commissioning process the building’s systems may be well tuned, buildings change over time, drifting farther and farther from their originally intended design. The result is increasingly inefficient building operations.

What can you do to avoid these problems and improve the long-term operations of your building? As an owner, building manager or operator, the set of strategies described in this guide provides the tools and techniques you need to prevent undetected problems and band-aid solutions.

Persistence of Savings Obtained from Continuous Commissioning SM

The persistence project is a study which investigates the savings in energy consumption of ten buildings that were commissioned between 1996 and 1997 by the Continuous Commissioning (CCSM) group at the Energy Systems Laboratory (ESL) at Texas A&M University. All buildings selected for the study are on the Texas A&M campus, and none received major capital retrofits. This study determined how much energy and dollars the commissioned buildings have saved and how persistently the savings have been maintained after CC activities were completed.

The savings results have been calculated from hourly monitored thermal and electrical data by using E-Model, a program for data processing, graphing, and modeling energy consumption data. The models before CC were used as the baseline. As a whole, chilled water and electric savings have degraded a little over time, and hot water savings are about the same. Factors that affect energy use such as Energy Management Control System (EMCS) settings, are discussed in this paper. The EMCS settings are presented as pre-CC, post-CC, and current control schemes. In the overall study, chilled water savings have been degraded in the rate of 2.67% per year, electric savings decreased 0.67% per year, and hot water savings have stayed about the same since CC. Savings results averaged during the last four years are 40% for chilled water, 62% for hot water, and 11% for electricity. The total savings for the 10 buildings are $4,255,000. For all 10 buildings, as a whole, savings obtained from Continuous Commissioning have generally persisted since the Continuous Commissioning was completed.

Is Commissioning Once Enough?

The Energy Systems Laboratory has developed a commissioning process called Continuous Commissioning^{SM} over the last decade. This process is used to resolve operating problems, improve comfort, optimize energy use, and sometimes to recommend retrofits. The process has produced average energy savings of about 20% without significant capital investment in well over 100 large buildings in which it has been implemented. Payback has virtually always been under 3 years with most at two years or less.

This paper describes the process and presents recent evidence of the need for follow-up commissioning when indicated by consumption increases. A case study is presented that specifically shows the value of this follow-up.

California Energy Commission
Public Interest Energy Research Program

HPCBS # E5P2.2T5b2

HPCBS

High Performance Commercial Building Systems

Persistence of Benefits from New Building Commissioning

Element 5. Integrated Commissioning and Diagnostics
Project 2.2 - Monitoring and Commissioning of Existing Buildings
Task 2.2.5 - Investigate the persistence of the benefits obtained from different types of commissioning and continuous commissionings

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Persistence of Benefits from New Building Commissioning

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ABSTRACT

The commissioning process is gaining increasing recognition as a cost-effective strategy for reducing commercial building energy use. Although the success and cost-effectiveness of commissioning activities depend on how well the benefits of commissioning persist over time, this aspect of commissioning is not well understood.

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Introduction

Complex building systems are becoming more prevalent in commercial buildings, yet building owners often find that their buildings do not operate at the expected level of performance. Several factors contribute to this lack of building performance. The building industry has become increasingly segmented between the trades, and building industry professionals have been forced to reduce their fees to compete in the prevailing low-bid environment. As a result, quality control mechanisms and building system documentation have been largely eliminated from the building development process, and installation and operational problems have become commonplace.

More and more building owners commission their buildings to verify that the intended design has been implemented and to improve the likelihood that the equipment will maintain this level of performance throughout its life. Commissioning is a systematic process of ensuring that all building systems perform interactively according to the documented design intent and the owner's operational needs (PECI, 1997). Building commissioning prevents problems from developing, anticipates and regulates system interactions, and implements a systematic method to meet the building's mechanical, electrical and control requirements. In correcting building problems, commissioning has been found to reduce repair and replacement costs, tenant complaints, indoor air quality problems, and liability and tenant turnover costs.

The fledgling commissioning industry, though growing every year, must resolve several issues to achieve greater penetration in the building industry and receive further support from utility energy efficiency programs. One of these issues is how well the measures that were fixed during commissioning persist over time. In August 2001, a California Energy Commission Public Interest Energy Research (PIER) project studied ten buildings that were commissioned as new buildings to address the persistence of benefits of commissioning. This study draws qualitative conclusions about the persistence of benefits from commissioning, focusing on three issues: how well the benefits of commissioning persist, the reasons for declining performance, and methods for improving persistence. A quantitative assessment of persistence by measure ("this measure has an expected persistence of X years") was outside the scope of this project. While this information would be desirable for cost-benefit analysis, a large number of buildings would be necessary to determine the life of each measure.

The Energy Systems Lab has conducted the only known studies on the persistence of commissioning benefits. Researchers studied the persistence of existing building commissioning at ten buildings on the Texas A&M campus and found a 17% increase in energy use over a period of two years (Turner et al., 2001). At these buildings, electricity, chilled water, and heating water use is metered hourly, which provided a sound basis for calibrated simulation and evaluation of savings degradation.

Methodology

The research proceeded according to the steps listed below. The description that follows provides details about each of these steps.

- Solicit and select buildings to participate
- Select measures to study from the commissioning documentation
- Define criteria for persistence
- Conduct interviews
- Perform site visits for selected buildings
- Determine reasons for persistence and methods for improving persistence

Solicit and select buildings

The solicitation and selection of buildings to participate in the study began with calls to California building owners and government representatives who had some form of commissioning at their building. After these contacts were insufficient to locate ten buildings, we contacted commissioning providers with projects in California and California utilities that had commissioning incentive programs.

To qualify for the study, the facility had to have been commissioned as a new building or major retrofit between two and eight years ago. Since buildings commissioned in California with adequate commissioning documentation were very difficult to find, we selected five buildings in the Pacific Northwest and five buildings in California. It was difficult to find buildings with the quality of commissioning documentation promoted by the Building Commissioning Association (BCA, 1999). Furthermore, it was not feasible to limit the study only to buildings that followed the full commissioning process. According to ASHRAE Guideline 1, the commissioning process begins during programming and design and follows through the construction, acceptance, and post-acceptance phases (ASHRAE, 1996). We studied the persistence of the best documented and most complete commissioning processes that were found. These projects included pre-functional checks and functional testing, but design-phase commissioning was not typically implemented.

Select Measures

For each building, we identified three to eight items that were documented and fixed during commissioning. The changes and repairs made during commissioning generally fell into three categories: hardware, control system, and documentation improvements. With a main focus on energy saving measures in this study, our first priority for studying persistence was to select the hardware and control system changes with the greatest energy implications. Additionally, measures that improved comfort or reliability had significant benefits to the owner and were possibilities for selection.

As we reviewed the commissioning documentation, the driving force behind the selection of measures was the amount of information available. We could only select measures that were implemented as a part of the commissioning process and had documented details about how the problems were fixed. Many measures were eliminated from potential study due to a lack of information in the commissioning documentation that would allow us to compare the current operation to the as-commissioned operation. A large number of measures were reported as "recommendations" or "pending" and therefore, were not selected.

With limited site visit and interview time, we selected measures that maximized the value of the study results. Control system fixes were chosen because these measures can have significant impact on energy use and often can be modified easily. Maintenance issues such as typical calibration errors and clogged filters were not studied because the persistence of these items depend more on routine maintenance than the benefits of the original commissioning process. We did not place high priority on checking hardware measures that are fairly static once they are fixed. For example, we did not study instances when the commissioning agent found that equipment was disconnected from the power supply. Finally, we did not include changes that resulted from design review, since only one building underwent design phase commissioning.

Excluding hardware fixes and design changes that are likely to persist will tend to underestimate the overall persistence of commissioning benefits. The act of choosing measures that were feasible to investigate in the time available adds additional selection bias. For example, we could not evaluate discharge air temperature cycling during cooling operation when the building was not calling for cooling. Due to building and measures selection bias, the results of this study are presented in a qualitative manner.

Define Persistence

Before the persistence of new construction commissioning benefits could be determined, we defined what it meant for a measure to persist. In most cases, persistence or lack of persistence was clear. But some measures do not persist in exactly the way they were initially fixed if they were modified to meet real operating conditions. For example, the discharge air temperature reset schedule might be slightly modified if comfort requirements could not be met using the setpoints initially implemented. Even if the original reset schedule was more energy efficient, if the modified reset schedule still significantly improved energy efficiency compared to the pre-commissioning operation, then we defined the measure to persist. If the reset schedule had been disabled or modified to decrease energy efficiency compared to the pre-commissioning operation, then the measure did not persist. In some cases, the persistence of a measure was subjective, since determining persistence required judging whether the change improved or reduced the effectiveness of the commissioning repair.

Conduct interviews

The person from the facilities staff with the most knowledge about the control system was interviewed by phone. This first interview focused on developing an understanding of the commissioning documentation and control system. To investigate the commissioning measures in detail, we selected six buildings for site visits. In the remainder of the buildings, we performed a second phone interview to discuss the current state of selected measures that were fixed during commissioning. The interviews and site visits gave us valuable insight into the reasons for persistence and the methods for improving persistence.

Perform site visits

Given the limited budget for the study, we were able to visit six of the ten buildings for approximately a half-day each. During each site visit, we examined the commissioning documentation, system drawings, O&M manuals, and operator training opportunities to help understand the resources available to the operations staff. We also investigated the persistence of selected measures that were fixed during commissioning at each building. While gaining an understanding of the current state of system operation and documentation, we assessed the environment that the facilities staff operates under, such as the support for training and the time available to troubleshoot – factors directly related to the persistence of benefits of commissioning.

Results

The results of this study can be broken into two categories: findings due to the difficulties in performing the study and findings due to studying the persistence of commissioning fixes. This section presents reasons why buildings were difficult to locate and reports the persistence of the measures studied. A discussion of the level of persistence of specific measures selected for the study must be preceded by stressing the value of the original commissioning process at each facility. The measures that were selected for study were a small subset of all the items fixed during the commissioning process, from 20 to over 100 commissioning items were documented at each site. Each building operator and engineer felt that an extensive commissioning effort was essential.

Identifying Appropriate Sites to Study

Identifying buildings in California that qualified for the study was a long and difficult process. We began contacting California building owners, commissioning agents, and utility representatives in August 2001. Forty-seven building contacts were made in California, resulting in only five California buildings participating by March 2002. In contrast, five buildings in Oregon were found to participate in the study with only twelve building contacts made. It may have been easier to find commissioned buildings in Oregon because there is a longer history of new building commissioning in the Pacific Northwest, relative to other parts of the U.S. The small sample size of buildings in each state did not allow us to determine if the commissioning process or persistence of benefits differed by state.

Through our efforts in finding buildings, we identified several reasons that California buildings were difficult to locate. First, commissioning summary reports often were not written. Second, if the reports were written, they were often not available to the owner or operators. Third, new construction commissioning activities did not seem to be widespread. Last, many potential measures listed in the commissioning reports could not be investigated because they were only recommendations and may not have been implemented during commissioning. These four reasons are expanded upon below.

The extra effort required to summarize the commissioning findings in a formal report was often not completed. Therefore, there were instances when the volumes of information produced through commissioning were not put in a summary or a systems manual that could be used by facilities staff to better understand their systems. One common format for the commissioning documentation was a series of memos (or "punchlists") that listed items for the contractors to fix. As these problems were fixed and removed from the list, the details of the changes often were not documented.

Even if the reports existed, owners and facility managers often did not have access to them. Commissioning documentation was typically filed away in storage, unavailable, and not organized for easy reference. Commissioning providers, utility representatives, and building staff that had access to these large volumes of documentation did not have sufficient incentive to spend the time sorting through this documentation. Six buildings that had gone through the commissioning process did not have any commissioning documentation available, and therefore, they could not be included in the study.

Buildings that were commissioned as new construction in California between two and eight years ago were difficult to find, although we found many existing building commissioning projects (often referred to as "retro-commissioning") in California. A number of utility programs in California have promoted retro-commissioning in the past, which may have directed the enthusiasm for commissioning toward existing buildings.

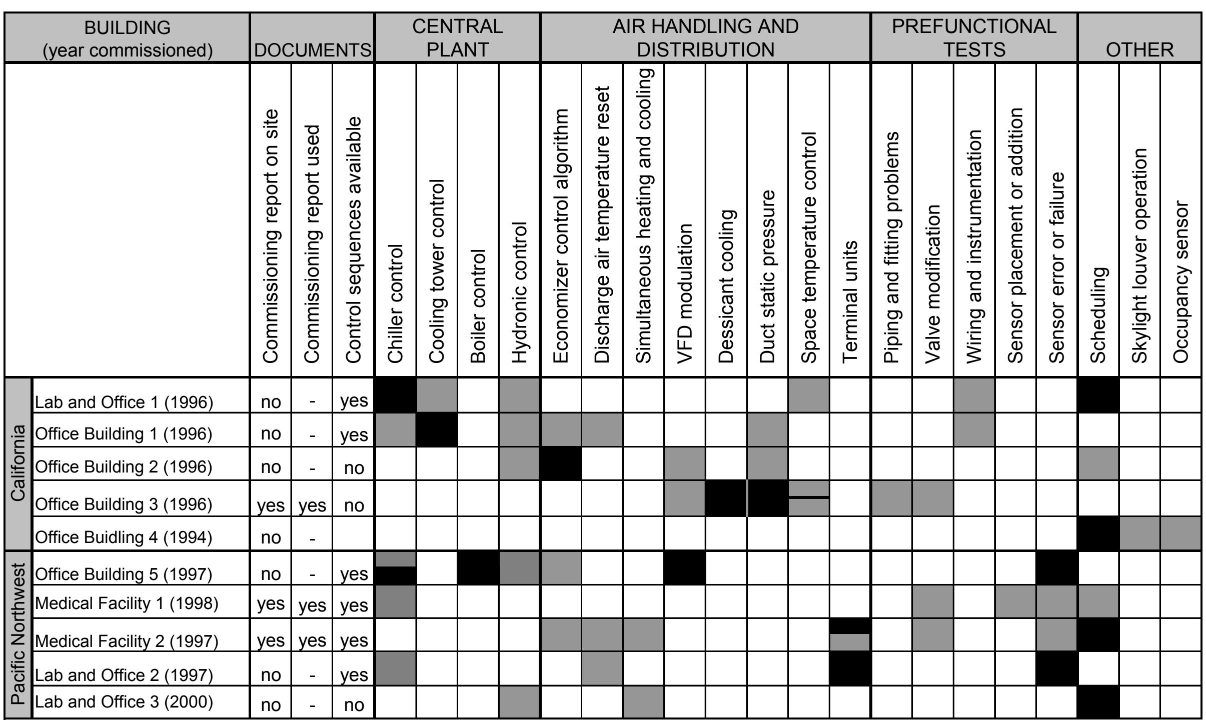
Commissioning ideally results in a fully operational building, but often in reality, a number of problems remain after commissioning is formally completed. We found that many items in the commissioning documentation had not been resolved, with a number of measures being labeled as "recommendations" or "pending". Problems left unresolved in the formal commissioning process are often expected to be implemented by operations staff during the first year(s). Since it was difficult to determine when or if these recommendations were followed, we did not classify these items as benefits of the commissioning process.

The lack of commissioning summary documentation and unresolved building problems point to the use of "commissioning" as an umbrella term for a variety of activities. This finding is supported by previous market research in California. The research identified that education is needed on the commissioning process, since the majority of owners defined commissioning as primarily the testing of systems (Haasl and Friedmann, 2001). Each commissioning process we encountered was defined differently. Troubleshooting activities during construction and simple checklists were referred to as commissioning. As we searched for buildings to participate, commissioning providers and owners told us, "this was not a good example of commissioning" since commissioning was inserted late in the construction process or had a contentious end. In effect, the persistence of the entire commissioning process, from design-phase to post-occupancy, was not investigated. Instead, we studied the variety of ways in which commissioning is implemented in practice.

Persistence of Specific Measures

The analysis of the persistence of specific measures is the heart of the study, from which the qualitative conclusions about persistence are drawn. The availability and use of the commissioning report and written sequences of operation were examined at all sites as possible factors for ensuring persistence. Figure 1 shows the measures that persisted (light gray squares) and did not persist (black squares) at each of the ten sites. A square split in half horizontally indicates that more than one measure was investigated in the category.

Figure 1. Persistence of equipment and controls fixed during commissioning. Light gray boxes show measures that persisted and black boxes show measures that did not persist.



Across the ten buildings studied, patterns for the types of commissioning fixes that persisted emerged. Fifty-five commissioning fixes were studied, and the large majority of the measures persisted. Items such as repiping and correcting wiring, once addressed, become relatively passive elements in the system, and therefore persisted. Other hardware fixes, such as adding a control valve, also tended to persist. When control programming code was modified, these changes often persisted, especially when occupant comfort was not compromised. Most of the hydronic control problems were fixed with control programming changes. Many design-phase fixes may also persist, but we were not able to study this issue since only one building had design-phase commissioning.

Control strategies that could easily be changed without modifying the programming code had the most problems with persistence. Four out of six occupancy schedules did not persist. Chilled water system control strategies did not persist in three out of eight cases. We limited our study of sensor issues to major sensor problems that were corrected during commissioning, such as sensor failure or excessively faulty readings. With these selection criteria applied, two out of four sensor repairs did not persist.

Additional Findings

Some new or "exotic" technologies did not have documented commissioning repairs, and thus were not selected for the study, but it became apparent that these measures tended to have problems. For example, evaporative cooling was disabled, demand control ventilation was not maintained, dimmable ballasts failed prematurely, desiccant cooling failed, and a natural ventilation cycle was problematic. While some of these persistence problems may have originated from a mechanical problem, the lack of operator training in these technologies contributed to the lack of persistence. Operators were often not trained in the proper control sequences and maintenance procedures for these systems.

Almost every operator interviewed stressed that design problems continue to require their attention. Nine of the buildings did not include standard design phase commissioning. Regardless of whether or not the design problems were fixed during commissioning, these problems are significant to persistence because operators that constantly battle design problems had less time to troubleshoot the performance of the rest of the building. The operators were aware of the lack of design phase commissioning and expressed that these problems should have been caught during a design review process.

Discussion

The findings on the persistence of the measures studied, coupled with an understanding of the operating environment at each building, point to probable reasons for declining or persisting performance and methods for improving persistence. These issues are discussed below.

Reasons for Lack of Persistence

Through this investigation, we identified three main reasons that benefits of commissioning did not persist: limited operator support and operator turnover, poor information transfer from the commissioning process, and a lack of performance tracking.

First, many of the operators we interviewed did not have adequate support for maintaining their buildings. This support includes training on the intended system operation and control sequences, the time to proactively assess building operation, and guidance and motivation for assessing energy use. Operator turnover was a major factor in the lack of knowledge about the intended system operation. Operators became more knowledgeable about the operation of their systems when they were involved in the commissioning process, and when these operators left the facility, the knowledge was often lost. In general, a new operator's training consisted of about a one-day walk-through with the former operator. In some cases, operator training at the end of the commissioning process was inadequate. At one building, forms for retesting a lighting system were provided with the commissioning report, but the operators were not trained on system operation.

In addition to operator training, transferring information from the commissioning process to building operation can occur through documentation. This information, in the form of a systems manual or a commissioning report, aids persistence by giving operators the necessary systems information to maintain equipment and troubleshoot problems. In almost every case, it was difficult to locate the commissioning report. For the buildings selected, seven out of ten commissioning reports were not available on-site.

Building engineers told us that commissioning focused on the short-term goal of providing a well-functioning building before the contractors leave. The commissioning documentation was a secondary benefit, but one that has implications for the future operation of the building. If commissioning documentation is not available, there may not be a reference point for how the building should run. For a new owner or operator, this lack of information limits the understanding of the intended operation, and ultimately could result in problems with troubleshooting and decreased performance. If the systems knowledge gained from the commissioning process is not available to the current operators through documentation or training, the value of commissioning is lessened in the long run.

Finally, the complexity of HVAC and lighting systems requires tracking to understand current performance. These activities were most often not established through commissioning or implemented after the final report was provided. The original commissioning process had little effect on the current operating environment or practices. Point histories and other control system data were only viewed to troubleshoot a specific problem, and almost never for performance tracking. It was clear that the operators were too busy responding to comfort complaints, performing routine maintenance, and troubleshooting problems to assess system efficiency. The baseline (as-commissioned) energy use was determined at only one building. The result is that operators would need to establish this baseline for comparison to the current performance.

Performance tracking begins with the utility bills. Operational problems such as off-hour operation and high base load energy consumption can be analyzed from utility bill data, but this practice occurred at only one building. In four out of the ten buildings, the building operations staff had been alerted by administration of suspicious changes in energy use, but the operators did not view the utility data directly. In five buildings, the operations staff did not have access to information about energy use.

Reasons for Persistence

The persistence of commissioning benefits was found to be highly dependent on the working environment for building engineers and maintenance staff. A working environment that was supportive of persistence included adequate operator training, dedicated operations staff with the time to study and optimize building operation, and an administrative focus on building performance and energy costs. Trained operators were knowledgeable about how the systems should operate and, with adequate time and motivation, they evaluated and improved building performance. In five buildings, operators participated in the commissioning process and came away with a good understanding of their systems. In addition, good system documentation in the form of a system manual served as a troubleshooting resource for operators at two buildings. Administrative staff can help enable a supportive working environment by placing a high priority on energy efficient systems and operator training. Only a few of the buildings studied seemed to operate in this supportive environment, and the measures investigated at these facilities had the highest rate of persistence.

Other measures persisted because there was no reason for change, and the measure could persist without maintenance. For example, if a controls repair during commissioning did not affect comfort in the subsequent years, then the controls most likely were not modified. Additionally, if a controls fix was buried in the programming code, most operators could not change it without hiring the controls contractor. Hardware repairs, often found during prefunctional tests, also tended to persist because there was no reason to intervene.

Four Methods for Improving Persistence

As the final goal for this study, we have identified ways in which persistence can be improved. These methods were developed with building engineers and operators in mind - the people who have the most control over the persistence of commissioning.

1. **Provide operators with training and support.** High operator turnover makes training and documentation critical to help ensure that the benefits of commissioning persist over time. A supportive environment for the building staff facilitates energy tracking and proactive troubleshooting. Building operator certification is one means of providing this advanced training (Price, 2001).

2. **Provide a complete systems manual at the end of the commissioning process**. The systems manual is the institutional memory for the building, and this information assists the staff in ensuring that the benefits of commissioning persist. The systems manual should include the design intent, system descriptions, sequences of operation, and a commissioning report. The commissioning report should summarize the deficiencies found during commissioning and set the baseline performance of the building. If the systems knowledge gained from the commissioning process is not available to the current operators, the value of commissioning is decreased in the long term.

3. **Track building performance.** New building commissioning efforts should help implement mechanisms for performance tracking, including what information to track,

how often to check it, and the magnitude of deviations to address. Using the baseline operation documented in the systems manual, operators can monitor whole building energy use and the efficiency of major equipment. The performance tracking system could also provide assistance in troubleshooting when deviations from the baseline are detected. These performance tracking activities are beginning to be automated by a number of diagnostic software tools (Friedman and Piette, 2001). Training for these tracking efforts is essential for success.

4. **Start commissioning in the design phase to prevent nagging design problems.** The most cost effective benefits of commissioning often occur during the design phase, when changes in design are made on paper, rather than during construction or after construction is complete. These changes would likely have high rates of persistence.

Next Steps

The preceding persistence analysis is based on evidence from a limited set of interviews and site visits, which has provided an understanding of the issues involved in persistence. In the second phase of the project during the summer of 2002, these findings will be supplemented with quantitative analysis. Using energy simulation software and utility data, we will create calibrated models of selected buildings. These simulations will use a detailed HVAC system model and typical load profiles (Liu and Claridge, 1998). The goal of the modeling is to quantify any observed degradation in energy performance, normalized for weather and building changes, and correlate any changes in performance with previous findings on the persistence of measures repaired during commissioning.

Conclusions and Future Study

We conclude that there was a lack of commissioning documentation and a limited level of support for operators in the commissioned buildings we studied. These factors did not promote the persistence of commissioning benefits. Without adequate system documentation, the baseline operation of the systems after commissioning was unknown. The current operation of the commissioned buildings studied often had a limited connection to the knowledge gained from the commissioning process. Even with these shortcomings, a large number of the measures fixed during the commissioning process persisted. The commissioning process was considered by operators and owners as essential to providing well-functioning HVAC and lighting systems - views that are supported by the large number of problems identified and resolved at each building.

As the first study of the persistence of commissioning benefits for new construction, this work has begun to address the reasons for persistence and lack of persistence. Through studying ten buildings, we have assessed the persistence of commissioning at an overview level. For cost-benefit analyses that require estimates of the "life" of commissioning repairs (commissioning of measure X in a new building has an expected persistence of Y years), a more involved analysis of the persistence of new building commissioning will be necessary. To do this type of quantitative analysis, a larger sample of buildings should be investigated. Future studies should attempt to investigate all measures that were documented during the commissioning process, which is an effort that may require analysis during multiple seasons.

A major goal of PIER projects is to bring research ideas into current practice. To put the findings from this study to practical use, a manual of guidelines for improving persistence should be developed. The guidelines would help direct building engineers and operators that wish to maintain the benefits of the new building commissioning process. Case studies could be carried out to examine and improve the effectiveness of the guideline implementation methods. In addition, building engineers and operators could participate in group training sessions on implementing the guidelines.

The success and cost-effectiveness of commissioning depends on how long the benefits persist. Without a good understanding of how to improve persistence, many benefits of commissioning will be lost. Bridging the gap between new building commissioning and day-to-day operations is a challenge that should continue to be addressed by the commissioning industry.

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Appreciation is extended to the building staff, owners, and commissioning providers that spent time relating their experiences and helping us investigate persistence. We also thank Linda Irvine at PECI for her support in this project.

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California Energy Commission
Public Interest Energy Research Program

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HPCBS

High Performance Commercial Building Systems

Strategies for Improving Persistence of Commissioning Benefits

Element 5. Integrated Commissioning and Diagnostics
Project 2.2 - Monitoring and Commissioning of Existing Buildings
Task 2.2.5 - Investigate the persistence of the benefits obtained from different types of commissioning and continuous commissionings

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DISCLAIMER

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Introduction

More and more building owners are turning to commissioning as a quality assurance strategy. Commissioning ensures that a new building works right from day one, and gets existing buildings back on track. Although at the end of the commissioning process the building's systems may be well tuned, buildings change over time, drifting farther and farther from their originally intended design. The result is increasingly inefficient building operations.

There are two primary reasons for declining performance:

- System repairs take a band-aid approach that keeps the building running but doesn't solve the root cause of the problem or take efficiency into account. For instance, changes that are implemented globally to the control system in response to a localized comfort problem can lead to energy waste.
- Hardware failures, lack of maintenance, and regular wear and tear cause problems that leave the building operating inefficiently but go undetected.

What can you do to avoid these problems and improve the long-term operations of your building? As an owner, building manager or operator, the set of strategies described in this guide provides the tools and techniques you need to prevent undetected problems and band-aid solutions.

Do the Benefits of Commissioning Last?

> "Without proper and ongoing training for our maintenance staff, coupled with the time to diagnose problems instead of putting band-aids on them, our up front efforts in commissioning will be short lived."
>
> **Owner's Representative**

A thorough commissioning or retrocommissioning process can get your systems running optimally in the short term, but how long will the benefits last? A recent study set out to answer this question.[1] The findings reveal that for new building

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[1] H. Friedman, A. Potter, T. Haasl, D. Claridge, and S. Cho., "Persistence of Benefits from New Building Commissioning" *Proc. of National Conference on Building Commissioning*, 2003. Available at **www.peci.org/papers/**.

Turner, W.D., Claridge, D.E., Deng, S., Cho, S., Liu, M., Hagge, T., Darnell, C.,Jr., and Bruner, H.,Jr., "Persistence of Savings Obtained from Continuous Commissioning[SM]," *Proc. of National Conference on Building Commissioning*, 2001.

The study had two parts: a new building commissioning study of 10 buildings between two and seven years old, and a study of ten buildings retro-commissioned two years earlier. The commissioning studies examined commissioning reports, control algorithms, EMCS point measurements, and energy use data to determine the persistence of select measures identified as commissioning, a majority of items identified as problems and fixed during commissioning ("fixes") continued to show benefits many years after commissioning. In new buildings, the most persistent, long-lasting benefits came in two areas: modifications to equipment that didn't require further adjustments, and control system programming changes that aren't easily accessed through the workstation user interface. However, every building studied had fixes that didn't last. These were overwhelmingly measures that are easily changed. The most problematic and least durable fixes were control strategies like schedules and setpoints that can be modified using a workstation interface.

In the retrocommissioning part of the study, energy savings that averaged 41% of total energy usage decreased by 17% over two years. Although savings decreased, the facilities still saved about 34% of their total energy usage compared to before retrocommissioning[2]. Component failures in two buildings did not impact comfort but increased energy consumption by $150,000 per year. In a number of cases, control parameters were changed that increased consumption slightly – about $50,000/yr total increase in energy costs in ten buildings that were enjoying about $1,000,000 per year in savings.

In all buildings, the long-term persistence of commissioning fixes and energy savings hinged on the abilities of the operators to troubleshoot and understand how the systems were supposed to operate.

Why Do Benefits Persist in Some Cases and Not Others?

A few key factors can make the difference between commissioning benefits that are long-lasting and those that are short-lived. One of the most important determinants is the working environment of building engineers and O&M staff. A workplace that **provides high-quality operator training, time to study and optimize building operation** and has an **management focused on optimizing building performance and reducing energy costs** is most likely to maintain a high level of building performance year after year.

A work environment with little operator training, turnover in operations staff, a lack of documentation or other method of transferring information from the commissioning process, as well as little or no performance tracking are all factors that contribute to declining building performance. These problems are opportunities to improve the persistence of benefits from commissioning.

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problems and fixed during commissioning. Operator and commissioning provider interviews were conducted to help determine reasons for persistence and methods of improving persistence.

[2] Claridge, D.E., Turner, W.D., Liu, M., Deng, S., Wei, G., Culp, C., Chen, H. and Cho, S.Y., "Is Commissioning Once Enough?," *Solutions for Energy Security & Facility Management Challenges: Proc. of the 25th WEEC*, Atlanta, GA, Oct. 9-11, 2002, pp. 29-36.

Operator Training and Turnover

Educated, experienced building operators are the key to an efficient building. Unfortunately, most building operators do not receive the support they need. This support includes training on system operation and control sequences, the time to proactively assess building operation and guidance and motivation for reducing energy use. Often a new operator's training consists of little more than a one-day walk-through with the former operator. Operator turnover also contributes to the problem. Every building operator who departs takes away valuable knowledge about the building's systems that is rarely passed on or written down, and thus typically is lost.

Commissioning Documentation

Information about building systems that is well-understood after the commissioning process will help building operators maintain the building's high level of performance for many years – *if that information is easily accessible after the commissioning process ends*. Good documentation is the best way to ensure a complete transfer of information from the commissioning provider to the O&M staff. This documentation supplies building operators with the information they need to maintain systems and equipment and troubleshoot problems. It also helps smooth the transition between building operators and provides a backbone for operator training. And although it may seem like an obvious point, it is important to not merely produce good building documentation during commissioning, but to store the records on-site in an organized and easily accessed way.

Performance Tracking

Performance tracking is a vital tool that helps building operators detect and diagnose problems early, before they lead to tenant comfort complaints, high energy costs and unexpected equipment failure. Lighting and HVAC systems have become so complex that continuous performance tracking (using trend logs and utility bills) is the key for building operators to know when systems aren't functioning properly. Unfortunately, a process for data gathering and analysis is not usually established by a commissioning provider or by the operating staff. Even when a process to gather data is determined, building operators are seldom trained to perform the analysis. Not to mention the fact that in most commercial facilities, operators are too busy responding to comfort complaints, performing routine maintenance, and troubleshooting problems to perform what are often thought of as "research" tasks. But without tracking, equipment failures that do not result in comfort problems can dramatically increase consumption and will seldom be discovered unless rigorous performance tracking is in place.

How Can You Improve Long-term Performance?

As a building owner, manager or operator, there are several things you can do to improve your building's long-term operations. This document treats each of these strategies in detail. They are:

- **Design Review**: Incorporate design review into your commissioning project to avoid problems that can hinder building performance throughout its life.
- **Building Documentation**: Document all building systems to aid operators in correctly operating and maintaining them.
- **Operator Training**: Provide thorough training for building operators on how to effectively and efficiently operate the building.
- **Building Benchmarking**: Benchmark building energy use as compared to other, similar buildings to identify need for improvement .
- **Energy Use Tracking**: Track energy use to monitor changes.
- **Trend Data Analysis:** Trend key system parameters to detect problems early and assess system performance.
- **Recommissioning:** Consider ongoing recommissioning activities to ensure that the building meets its current needs.

Design Review

> *"It works per design, but does the design work?"*
>
> **Building Operator, explaining why design phase commissioning is important**

Why Is Design Review Important?

Many buildings never recover from serious design flaws. Design problems vary greatly, but their result is often the same: building operators are forced to spend time working around the design problems, cutting into their time left to troubleshoot the building's other systems. Preventing the problems that can plague a building throughout its life is the role of design phase commissioning.

Constructing a building is a complex manufacturing process, and even with the most diligent and experienced design team things can go wrong. Most manufacturers wouldn't think of selling their product straight off the line without quality control, and neither should building developers, owners, and contractors. In short, design phase commissioning is a quality control check for new building design. It brings the talent and field expertise of an experienced engineer on board early in a project when it is less costly and disruptive to make improvements and corrections to the building design.

As many as one-third of major commissioning problems can be traced back to the design phase of the project.[3] Problems in a building's design become the building operator's problem for life. Below is a sampling of the problems discovered during the new building persistence study of ten buildings:

- Major gaps in the building envelope created very high infiltration rates, leading to frozen sprinklers and poor occupant comfort.
- Outdoor air intake and exhaust locations promoted the recirculation of exhaust air, resulting in poor economizer cycle performance (5-7°F increase in outdoor air temperature due to mixing). The operating staff believed that if the problem could be eliminated, they would be able to delay the start of the chillers for 4 or 5°F above the current start-up temperature.
- Poor chiller performance and incorrect cooling tower sizing was still unresolved over two years after the building was occupied. As a result, the chilled water system was disabled and an adjacent building's chilled water system was used instead.

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[3] David Sellers. "Using Utility Bills and Average Daily Energy Consumption to Target Commissioning Efforts and Track Building Performance" *International Conference for Enhanced Building Operations*: July 16-19, 2001.

- Inaccurate design load calculations and high minimum flow rates led to overcooled interior zones and high reheat use.
- Smaller chiller would not stay online to improper secondary chilled water pump sizing. As a result, the large chiller had to be used even at low loads.

What Happens During Design Review?

Design review provides an opportunity for comments on the design at various stages of development, noting potential system performance problems, energy-efficiency improvements, indoor environmental quality issues, O&M concerns, and other issues. The following list shows just a few topics usually covered during design review. Addressing these issues improves long-term building performance and helps avoid the design flaws that cause ongoing problems and monopolize a building operator's time:

1. **Test Ports:** In order to accurately calibrate, test, and maintain critical sensors, test ports are necessary. For example, including a second sensing well at temperature sensor locations will allow the installed sensor to be spot checked for accuracy.
2. **Equipment Accessibility:** Dampers, pumps, actuators, motors, and coils need to be accessible for maintenance. For example, fire and smoke dampers containing sensing elements, linkages and actuators that are located inside the duct must be accessible for service and inspection. In design documents, these access doors are often blocked by architectural features or merely overlooked.
3. **Load Calculations and Minimum Flow Settings**: Reviewing load calculations can reveal opportunities to reduce operating costs and system first costs. Simply put, most new buildings are overdesigned: they are built to function optimally under conditions they'll probably never see. An EPA study of 20 buildings found cooling plants that were an average of 69% oversized[4]. The most common reasons for oversizing are:
    - Real equipment loads are seldom at full nameplate values.
    - Diversity (not all equipment will be in full use at the same time) further reduces peak equipment loads.
    - Real occupant loads are seldom as high as design loads.

    As a result of these "worst case scenario" design practices, peak cooling and heating loads are usually not as high as designed. A good understanding of the *real* peak loads rather than overestimations can lead to energy savings over the life of the building. In addition to energy savings, reducing the size

[4] Cooling plant oversizing ranged from 6% to 243%. The study was completed in September 1995 using data from Energy Star Showcase Buildings.

of a piece of equipment reduces the necessary electrical capacity, and the system requires smaller starters and VSDs.

4. **Control System Sequences and Point Lists:** Design review should include examining the evolving control sequences and points lists to be sure they reflect design intent. For an example, see the discussion of the consequences of poorly defined control system sequences, starting on page 9. Reviewing the points lists for sensors that allow the system to be commissioned will reduce commissioning costs.
5. **Standard Design Details:** Careful detailing assures that duct and pipe fittings minimize system pressure drops, which results in energy savings over the life of the building. Checking standard details is critical because they are replicated over and over throughout the design.

When Do You Perform Design Review?

1. Leave enough time for multiple design reviews. It is much easier and less expensive to make changes on paper than once something is built.
2. In general, become involved as early as possible to bring up issues before significant engineering time has been invested. Otherwise, designers may not have the budget to act on suggestions.
3. Review the design near the end of schematic design to identify an unworkable concept or introduce an energy efficient configuration.
4. Flag problems during design development by reviewing the design once or twice before construction documents are complete. Look for big problems like poor equipment room layout early in the process.
5. Check that the 95% complete construction documents have addressed the design issues flagged in earlier design reviews.

Design Review Resources

Building Commissioning Guidelines. Energy Design Resources, administered by Pacific Gas & Electric Company, San Diego Gas and Electric, Southern California Edison, Southern California Gas Company, 2001. Available at **www.energydesignresources.com/publications/comm_handbook/**

Design Review. Design Brief for Energy Design Resources. Available at **www.energydesignresources.com/publications/design_briefs/**

Design Details. Design Brief for Energy Design Resources. Available at **www.energydesignresources.com/publications/design_briefs/**

Why Design Phase Commissioning Makes Good Sense for Health Care Facilities. David Sellers and Karl Stum. Available at **www.peci.org/papers/ashe.pdf**

Building Documentation

Operations and maintenance staff need clear, accurate building documentation to effectively operate building systems, but these documents are often missing and, when available, are rarely written with building operators in mind.

Why document your building's systems?

At first glance, spending money solely on documentation may seem like an "extra". In the current construction environment, it is not common practice to provide documentation of design intent and write sequences for all modes of operation. In fact, most owners feel lucky to complete a project with updated as-built drawings and complete O&M manuals. Why ask for more?

Good system documentation helps ensure that the benefits of commissioning persist. At the end of a thorough commissioning process, the commissioning provider, building operators (if onsite), and contractors have become intimately familiar with all of the building systems as they test, troubleshoot, and resolve issues. How can an owner keep this valuable knowledge with the building for the life of the facility? Without a way to document this knowledge, much of the long-term value of commissioning is lost. By gathering and organizing certain information, the documentation becomes the memory of the building.

Which Documentation is the Most Important?

Building owners and managers should consider the following three pieces of documentation the highest priority:

1. Final design intent documentation

The starting point for any design is to understand its goals. Documenting these goals summarizes the owner's project requirements for the building (the expectations of how it will be used and operated) and the acceptance criteria that were used to meet those requirements. With clear design intent documentation, all parties will understand in detail the owner's goals for the project.

> **Example:** Consider what happened when the designers of a major retrofit in a spec office building didn't take the time to think about design intent.
>
> Low first cost was communicated as the top priority, with no formal design intent documents written. As a result, inefficient HVAC systems were installed with no attention to indoor air quality. The packaged rooftop unit control strategy resulted in compressor short-cycling and poor comfort due to inadequate dehumidification. Moisture condensed on the ducts, leading to serious indoor air quality problems and threats of litigation. In this case, the lack of time spent thinking about design intent early in the project led to serious problems down the road.

2. Sequences of operation

Sequences of operation are very useful to building operators. Without a thorough understanding of how the control system should operate, building operators have difficulty verifying correct operation and troubleshooting problems. For each HVAC and lighting system, a detailed sequence of operation should be created and updated as necessary for all operating modes. Often the sequences provided on the contract drawings and duplicated in the specification provide a good overview of how the system is intended to perform but fail to address critical details that make or break the success of the installed system. Interactions between systems are often left out - for example, the relation of building pressure control and economizer operation.

Example: Consider the following air handling unit sequence of operation, typical of today's contract documents.

The control system shall modulate the economizer dampers, heating valve and cooling valve in sequence as required to maintain the discharge set point of the system. The discharge set point shall be reset from 55°F to 65°F as a function of the outdoor air temperature.

At first glance, the sequence may seem reasonable. But there are many unanswered questions. A project engineer might ask the following questions when considering the system under all modes of operation:

1. How is the minimum outdoor air setting maintained?
2. What is the optimal point in the cooling mode for locking out the economizer?
3. Will one control signal serve all actuators, or will each actuator have independent control signals?
4. What positions should the actuators return to when the unit is shut down?
5. Is a freezestat necessary?
6. What is the relationship between outdoor air temperature and discharge air reset setpoint?
7. Is the reset schedule in effect year round or only when dehumidification is not an issue?
8. What alarms should be programmed?
9. Are the set points adjustable without reprogramming the system?
10. Are the safety devices and interlocks independent of the DDC system?

For new construction, if issues like these are not cleared up before the contractor develops the control program, the door is left open for many potentially costly problems. Here are just a few likely scenarios:

- No one catches the problem. The building operator receives complaints and calls in a contractor to help find a solution, or just works around the issue, meanwhile raising operating costs and shortening equipment life.
- The commissioning provider catches the problem during functional testing. Correction requires a change order.
- An experienced controls programmer identifies the problem but requires a change order from the owner to make corrections. If the owner refuses to issue a change order the sequence remains incorrect.
- An experienced controls programmer identifies and corrects the problem but doesn't document it in the project construction documents. In the future, operators are not sure if the problem has been addressed.

For existing building projects, the sequences should also be carefully documented, with emphasis on describing the reasons for all changes. Improvements are more likely to persist when operators understand the rationale for the changes and agree with their implementation.

3. System diagrams

Creating a system diagram is an invaluable tool for troubleshooting throughout the life of the facility. A system diagram enables the user to see the entire process of heating, cooling, and ventilating the spaces and visualize potential interactions. A system diagram depicts the *entire system* in schematic format, rather than simply *pieces* of the system.

A system diagram is often confused with a schematic drawing, but the distinction is important. To gain a better understanding of the differences, compare Figure 1 with Figure 2. Both drawings show the same system. Figure 1 is a schematic presented on the contract drawings; Figure 2 is a system diagram, summarized from multiple schematic drawings.

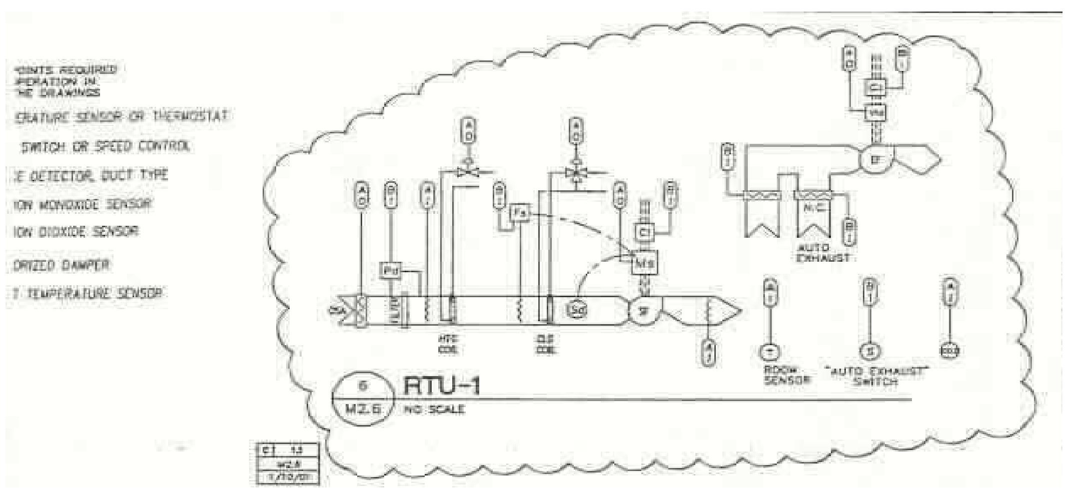

Figure 1: System schematic from the mechanical drawings
This schematic does a poor job of showing how the system works as a whole.

A well-developed air handling system diagram includes the following features:

- The system's complete airflow path is shown, from point of entry into the building to point of exit.
- All significant components are labeled, including dampers, coils, filters, fans and all final control elements and sensors.
- Equipment operating parameters are stated, including flow ratings, horsepower ratings and other pertinent operating data.

Inaccurate drawings are not an uncommon occurrence. A system diagram laid out in the simplest way possible goes a long way to clarifying the intended operation of the entire system. On projects where a system diagram does not exist, developing one is a good first step. Once completed, the system diagram serves as the schematic on the contract drawings, illustrates other system documentation and can be incorporated into the DDC terminal interface.

Example:

Building operators at a large hotel repeatedly encountered problems keeping their chilled water system online. They used the drawing on the control system graphical interface to troubleshoot these problems, but the system just didn't seem to respond to their control modifications in the predicted way. For years, operators tolerated the erratic equipment until a commissioning provider traced out the actual chilled water piping to find the cause of the problems. It turned out that three different drawings existed to describe the chilled water plant and careful examination indicated that none of the three drawings matched. Furthermore, none of these drawings accurately represented the installed system. With a careful untangling of the piping in the field, the commissioning provider identified incorrect piping layout (compared to the correct drawing) and an out of place check valve.

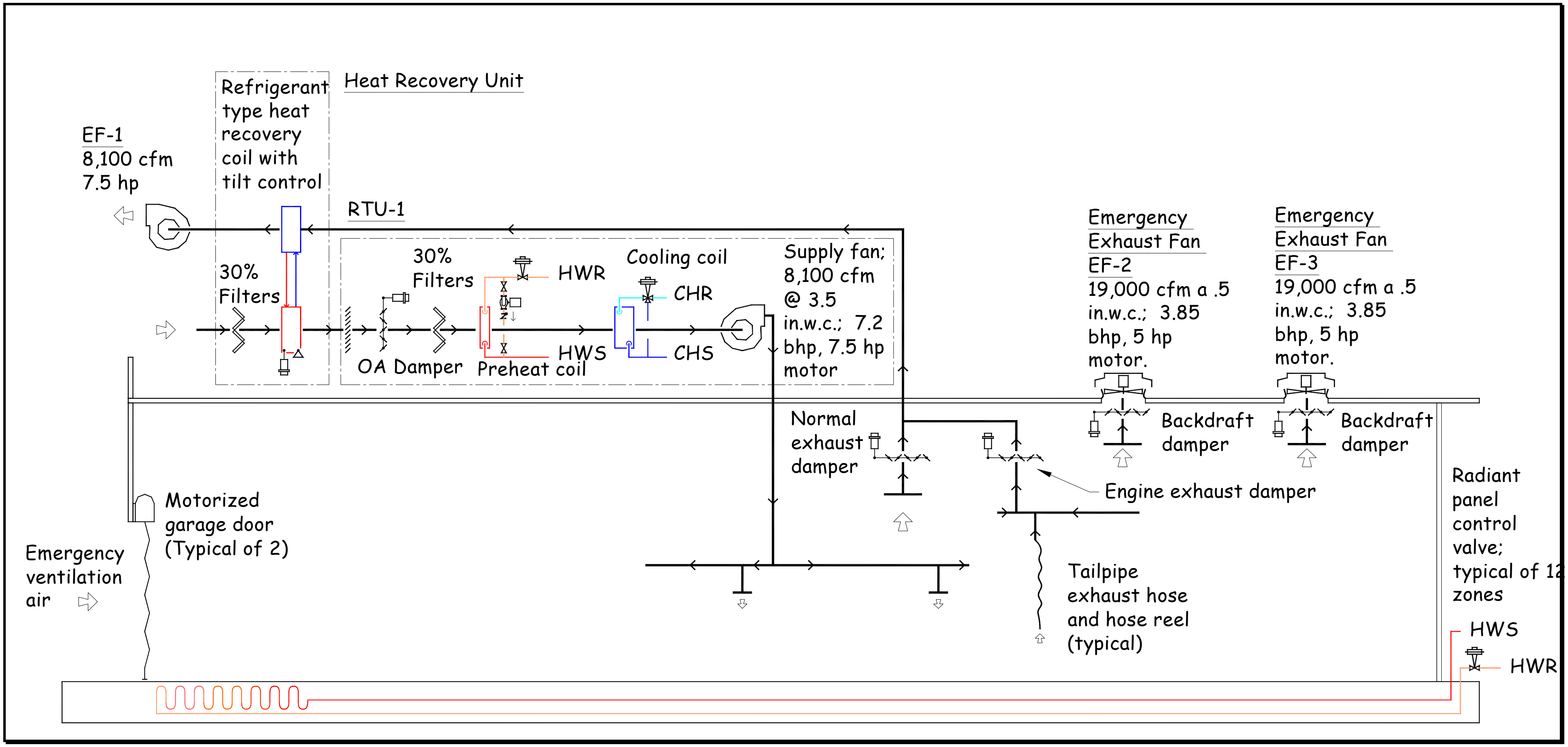

Figure 2: System diagram developed for the air handler in Figure 1.

This well-developed system diagram does a good job of showing all the important components of a system in a single drawing.

4. Other Important Documents

In addition to the three top priority documents listed above, there are other documents that will give the building operators the "big picture" perspective they need without overwhelming detail.

- **Operator's log:** This log keeps record of significant events such as equipment replacement, maintenance or testing, and problems and their resolution. If possible, the log should be kept electronically to allow for easy searching. This document will prove invaluable for building operators who, facing a problem, find themselves asking "didn't this happen before"?
- **Commissioning summary report:** A commissioning summary report lists the deficiencies found during commissioning and their resolution. The report documents the baseline performance of the building, and, if possible, should include the commissioning plan and a copy of the verified testing and balancing report. The location of the start-up checklists and completed functional testing procedures should be referenced.
- **General description of facility and systems:** This summary of useful building characteristics and major equipment and their locations is useful as an overview for new operators or contractors.
- **As-built documents:** These marked-up construction drawings include changes made to the design during and after construction. They will be used by facility staff for troubleshooting and maintenance activities and should be continuously updated after any further changes to building systems.
- **Detailed description of each system:** A description of each system's capabilities, baseline performance and troubleshooting tips is a handy reference. The description should also references seasonal changeover and maintenance procedures.
- **Location of all control sensors and test ports:** This documentation allows building operators to quickly reference the location of control sensors and test ports, making maintaining and testing the systems easier.
- **Capabilities and conventions of the DDC system:** Documenting the DDC system trending procedures and capabilities streamlines trending and can avoid hours of frustration trying to match point names to their location.

Who documents the building's systems?

Ideally the people involved in constructing the building – the owner, designer, engineers and contractors – take the time to document the building's systems and intended operations. This is the easiest and most cost-effective time to gather documentation – while it's still fresh in everyone's mind.

Assembling or recreating building documentation years after construction, when most of the responsible parties are long gone, can be difficult. This documentation of an existing building is expensive because the window of opportunity to download the designer and controls contractor's knowledge has passed. Even though it is difficult to compile the intended system operation, the process will help building operators learn about their facility. A good time to create documentation for an existing building is during a retrofit or a retrocommissioning process, while there is momentum and focus on optimizing system operations.

Compiling important building documentation in one place is often called a *systems manual*. The systems manual provides the necessary information to understand, operate, and maintain the building systems. There are a variety of ways to put together a systems manual – the important thing is that the essential information about how to operate the building is included (see the list of important documentation starting on page 8), as well as the lessons learned from the commissioning process. Input from your operators can help prioritize what to include in the systems manual. Additionally, the systems manual should be continuously updated as modifications are made – it is helpful to define who will "own" the systems manual and how it will be maintained.[5]

Documentation Resources

Guideline 1 – 1996 The HVAC Commissioning Process. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), Available at **www.ashrae.org**

Guideline 0 - (public review version) The Commissioning Process. American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

[5] Gillespie, Ken, *Developing Systems Manuals for Existing Buildings in a Corporate Environment*, National Conference on Building Commissioning: May 20-22, 2003, PECI.

Operator Training

"For ten years, state efficiency programs have been giving us money for technology and designing technical solutions for energy efficiency. While that has been nice, much of it has missed the mark – where we really needed the help was in operations and maintenance."

School O&M Administrator

"There is a real shortage of well-trained people who can effectively operate and maintain buildings. Where are we going to find them? It's scary. My management is beginning to understand trained building operators are crucial to risk management."

Chief Engineer, Property Management Firm, Portland, OR[6]

Why is Training Important?

A well designed training plan supported by the operations and maintenance manuals, systems documentation, and videotapes of the training sessions will help ensure that the building is operated efficiently and that the benefits associated with the commissioning process persist for the life of the building.

There are many real-life situations where better training for building operators could have prevented problems. For example, in one small office building, the operator was never taught how to service the carefully designed daylighting control system. As a result, the louvers rarely operated to vary lighting level according to need. In a laboratory and office building, the operator disabled the evaporative cooling system because he wasn't trained on how to maintain it, and it became a nuisance to operate. As a result, the building owner's investment in energy efficiency was wasted.

Perhaps the most common area for improvement in building operator training lies in the trending functions of the DDC system. The wide gap between the capabilities of these complex systems and the ability of building operators to fully utilize them leads to missed opportunities every day, in both the early identification of building problems and significant energy savings.

Is There Training Available for Building Operators?

Training opportunities exist for building operators during the commissioning process, through manufacturers and vendors, in operator certification programs, and using building documentation.

[6]Quoted in Putnam, et. al., 2002. Original source: Vince Schueler, *Building Operator Certification in the Pacific Northwest : A Preliminary Business Plan,* Washington State Energy Office, 1995.

Training During Commissioning

Involving operating staff in the commissioning process during construction observation, start-up, and functional testing can provide invaluable training that is difficult to duplicate in a classroom setting. Early involvement allows the operating staff to observe the fabrication of the systems and building – and reveals the exact configuration of components that will be concealed when the building is complete. Participating during start-up and testing provides first-hand insight into the operating fundamentals of the systems and equipment. This involvement also exposes operators to the nuances of system operation and the resolution of any difficulties produced by these issues. When running the building, these experiences will help operators respond more effectively to unusual situations. In addition, exposure to the functional testing process will give operators hands-on training in some of the test sequences that they will later use as part of an ongoing commissioning program or to troubleshoot operational issues that arise.

Training during the retrocommissioning process is similar to new construction commissioning in the sense that building operating staff should be involved in all phases of the process. This training should start with the installation of any monitoring equipment that is installed and should continue with staff participation in implementation of changes. The staff should fully understand the reasons for all measures implemented and approve of the solutions. A workshop for building staff to discuss the findings of the retrocommissioning process is valuable.

Manufacturer/Vendor Training

Owners of large buildings or complexes may benefit from sending their key personnel to factory schools run by equipment manufacturers, for example, air handling systems, chillers, pumps, and steam specialties. Although these programs apply specifically to the manufacturer's equipment, much of the knowledge gained is transferable to other manufacturer's equipment. The cost of this training may seem high, but the benefits are also large in terms of operating savings and avoided costs.

If your building uses a DDC system, sending members of the operating staff to a complete training course run by its manufacturer can pay back very quickly from energy cost savings and reduced comfort complaints. DDC systems offer the ability to perform complicated energy-efficient control strategies but are commonly underutilized due to a lack of training. When O&M staff understand the software control logic of the DDC system, they can customize the control of equipment for a variety of conditions. But without proper training, the DDC system often becomes a burden for building staff. Some systems become scapegoats for comfort and control problems and staff may eventually disable them.

Along with training on control logic, training on DDC system maintenance activities are also important. For example, certain sensors (such as the mixed air sensor and the supply air sensor) are more critical for energy efficiency and comfort and should be calibrated more frequently.

Building Operator Certification

The Building Operator Certification™ (BOC) program is one avenue for ongoing training for building operators. This competency-based training and certification program is designed specifically to help building operators improve the energy efficiency of commercial buildings. It provides training in HVAC systems, building systems overview, energy conservation, and indoor air quality. Operators earn certification by attending training sessions and completing project assignments in their own facilities.[7]

The BOC program was started by the Northwest Energy Efficiency Alliance in 1997. To date, over 1000 operators have been certified.[8] Employers who send their operators to the training include: US Navy, General Services Administration, Boeing, Cisco Systems, Immunex, Marriott, Federal and State agencies, medical centers, and over 40 school districts and twenty municipalities across the country.

BOC Course Topics

Level I
Building Systems Overview
Energy Conservation Techniques
HVAC Systems and Controls
Efficient Lighting Fundamentals
Maintenance and Related Codes
Indoor Air Quality
Facility Electrical Systems

Level II
Preventive Maintenance
Advanced Electrical Diagnostics
HVAC Troubleshooting & Maintenance
HVAC Controls and Optimization

Electives
Introduction to Commissioning
Advanced Indoor Air Quality
Motors in Facilities Water Efficiency for Building Operators
Mastering Electric Control Circuits
Electric Motor Management

BOC offers two levels of certification. Each level requires approximately 50 hours of classroom training and a set of project assignments. BOC certification courses are now offered at nine locations across California. The website lists schedules for upcoming trainings (www.theboc.info).

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[7] Price, Stan, *Building Operator Certification and Its Relationship to Commissioning and the Persistence of Savings*, National Conference on Building Commissioning, 2001.

[8] Putnam, Cynthia et al, *BOC Experiences Coast to Coast: Helping building operators improve the energy-efficient operation of their buildings*, National Conference on Building Commissioning: 2003.

BOMI

BOMI (Building Owners and Managers Institute) provides training opportunities for achieving two different professional designations: Systems Maintenance Technician® (SMT) & Systems Maintenance Administrator® (SMA). BOMI's SMT and SMA designation programs offer instruction in maintenance technologies for managing building systems in an energy-efficient and cost-effective way.

BOMI has been providing commercial property education since 1970, with more than 19,000 graduates. Courses in California are available –the website includes locations and more information(www.bomi-edu.org).

BOMI Course Topics

Systems Maintenance Technician
Refrigeration Systems and Accessories
Air Handling, Water Treatment, and Plumbing Systems
Electrical Systems and Illumination
Boilers, Heating Systems, and Applied Mathematics
Energy Management and Controls

Systems Maintenance Administrator
All five SMT courses above
Administration
Building Design and Maintenance
Environmental Health and Safety

Training for Newly Hired Operators

When a building operator leaves, his or her experience with the building systems will often be lost – unless precautionary measures are taken. There are several effective ways to transfer information from one operator to another.

A new operator can be trained on the building's systems through an in-depth building walk-through with an existing building operator. The new operator can review existing documentation as a part of this training. The final hand-over may involve going through the building documentation with the new operator, especially the design intent, system diagrams (or control diagrams), and sequences of operation. A well-executed handover will go a long way toward ensuring building performance.

Suggested Training Topics

As with all training, instruction should be structured to meet the needs of the building staff. Suggested training topics include:

- Descriptions of equipment and systems and their warranties
- Equipment start-up and shut-down procedures, operation in normal and emergency modes, seasonal changeover, and manual/automatic control.
- Operation and adjustment of dampers, valves, and controls.
- Review of system documentation and their location on-site.

- Common troubleshooting problems, their causes and corrective actions.
- Requirements and schedules for maintenance
- Health and safety issues
- Recommendations for special tools and spare parts inventory
- Emergency procedures

Training Resources

Additional Building Operator Certification information available at **www.theboc.info**

Additional BOMI Institute certification information available at **www.bomi-edu.org**

Fifteen O&M Best Practices for Energy-Efficient Buildings, PECI O&M Best Practices Series. Available at **www.peci.org/om/15best.pdf**

O&M Assessments: Enhancing Energy-Efficient Operation, PECI O&M Best Practices Series. Available at **www.peci.org/om/assess.pdf**

Putting the "O" Back in O&M: Best Practices in Preventive Operations, Tracking, and Scheduling, PECI O&M Best Practices Series. Available at **http://www.peci.org/om/putoback.pdf**

Building Benchmarking

> "The ability to benchmark a building's performance and use the statistical data to continually improve performance fits with Harwood's goals. The result is reduced leasing costs, better distribution of budget dollars, and the fostering of a one-to-one marketing relationship between HMS and our clients. We become more than simply a developer or landlord to them. We gain the respect of a trusted advisor."
>
> **Doug Walker, President, Harwood Management Services**

In order to improve building performance and efficiency, you must first evaluate your current operating practices. This practice is called benchmarking, and there are several free tools at your disposal to assist with the process. Benchmarking has become a popular place to begin studying energy use. Benchmarking a building measures the energy use of *your* building relative to *other* buildings.

Benchmarking provides a way for building owners and operators to track their energy use over time and see how they stack up against the competition. Buildings with top-of-their-class energy use probably didn't achieve this rating without conscious improvement of their O&M practices. Thus the act of benchmarking can drive building owners and managers to greater achievements in energy efficiency. As an owner or manager of multiple facilities, building benchmarking can help you compare your buildings to one another and prioritize improvements. These benchmarking activities can also be accomplished using Energy Information Systems (EIS), discussed starting on page 26.

Below we take a close look at two benchmarking tools: the ENERGY STAR Portfolio Manager and the Cal-Arch Building Energy Reference Tool.

ENERGY STAR Portfolio Manager

The ENERGY STAR Portfolio Manager is the most widely used building benchmarking tool. It was developed by the US Environmental Protection Agency (EPA) and since 1999, over 2,220 million total square feet have been benchmarked using this rating system. This is approximately 12% of the total building market.

After this web-based tool uses the energy bills and building characteristics you supply to complete its calculations, it reports a score that indicates where your building ranks, compared to a pool of similar buildings. If your building scores higher than 75% of the competition, you can apply for the ENERGY STAR label (buildings must also pass an inspection for air quality and comfort by a certified engineer). With their benchmarking tool and award system, the EPA has developed a systematic way to rank the energy efficiency of buildings against their peers, track improvements, and receive credit for them.

How are buildings of different sizes compared? Benchmarking energy efficiency is most often done in units called "energy use intensity", or EUI. EUI is calculated by dividing total energy use by gross building square feet. Looking at energy use per square foot levels the playing field between small and large buildings.

Will the heat wave this summer penalize my benchmarking score? The ENERGY STAR Portfolio Manager takes the energy consumption data that you report for a specific year and calculates the building's expected energy consumption for a *normal* weather year (weather data collected over the past 30 years). This process is called weather normalization.

Does a building that's filled to capacity compete head-to-head with a building that is practically empty? It's a simple fact that the more occupants there are, the more energy the building may use. For this reason, the Portfolio Manager applies calculations that predict energy usage based on the number of occupants.

What about climate? If my building is in Palm Springs, where we use air conditioning all the time, will I automatically rank lower than a building in San Francisco, where they need less cooling? The amount of heating and cooling required for comfortable building conditions in each region is also taken into account using predictive calculations.

The **ENERGY STAR Portfolio Manager** takes into account factors that are outside of your control as a building manager. If you can't control them, then you aren't penalized for them.

As an example, the score for an office building takes into account the following factors:

1. Building gross square footage
2. Location (climate) and weather
3. Occupancy
4. Hours of operation
5. Number of computers
6. Space use (computer data center, garage, offices)

There are even more factors that skew the ability to compare your building to others (see the sidebar for details). The ENERGY STAR Portfolio Manager takes these factors into the equation to compare your building against your counterparts across the country.

Cal-Arch Building Energy Reference Tool for California Buildings

The Cal-Arch Building Energy Reference Tool provides a simple way to benchmark buildings using a database of only California buildings. Unlike the ENERGY STAR tool, Cal-Arch doesn't take building attributes like occupancy, climate, or hours of operation into account. It simply ranks your building's energy consumption per square foot.

This type of benchmarking is more straightforward and much faster to do because it requires less inputs. The downside is that, as a building manager or owner, it doesn't correct for other factors that may affect energy use like occupancy or operating hours. For example, Cal-Arch may rate a building among the worst when it consumes a great deal of energy, even though it supports an astronomical number of occupants. Alternately, a building may be rated among the most efficient with operating hours that are 50% less than other buildings. Cal-Arch is most effective when ranking your building against others in its sector (for example: office, healthcare, lodging, school) because these buildings share common characteristics that level the playing field.

Required inputs for Cal-Arch include building floor area and one year of energy consumption from all sources. Figure 3 shows an example output of the Cal-Arch benchmarking tool. The arrow points to the EUI of a sample building. In this example, notice that the building falls into the range of 120-160 kBtu/sqft-yr along with over 40 other office buildings in a similar climate zone. This building falls in the 64th percentile – that is, 64% of the buildings have lower energy use intensities than the example building. The black line shows the percentile rank for all the EUI values and is read using the right axis.

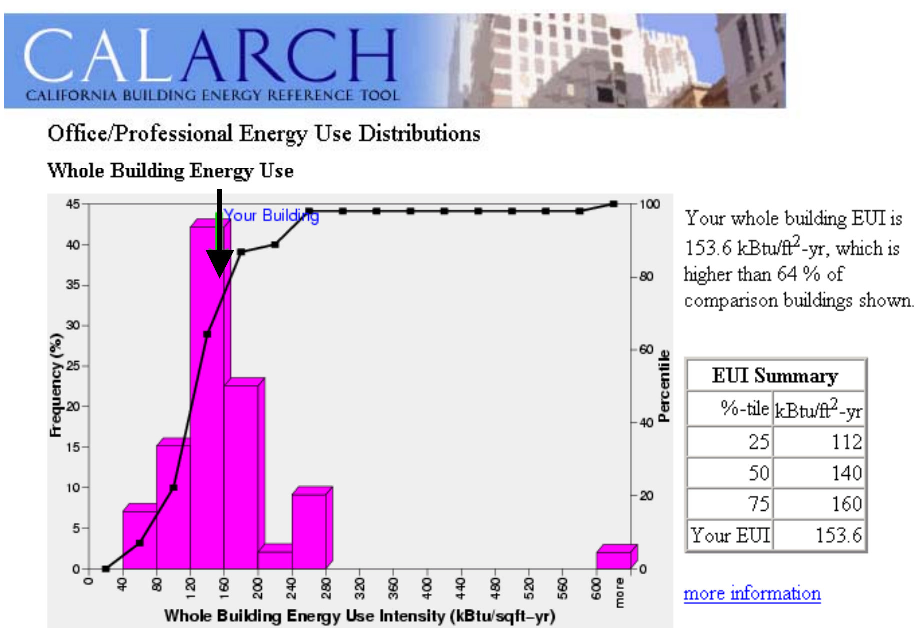

Figure 3: Cal-Arch benchmarking tool using source energy

Should you select "site" or "source" in the Cal-arch benchmarking tool? The Cal-Arch benchmarking tool asks how you want energy use to be reported: site or source. What's the difference? *Site energy* refers to the energy delivered to your building, which can be found in your energy bills. Although site energy is easily found in your energy bills, it does not take into account the generation and transportation energy that it took to get the energy to your site. This is where source energy enters the picture.

Source energy refers to the total amount of energy consumed - including the costs of getting the energy to you. Using source energy helps you understand the difference in environmental impacts between the use of different fuels. For instance, reporting your source energy consumption will take into account the amount of energy it took to generate the electricity at the power plant and transmit it over power lines to you. For most locations, the source energy for electricity is about three times the site energy. That is, for every 100 Btus of gas or coal a power plant burns, it generates about 33 Btus of electricity. Site and source natural gas usage is nearly the same because it takes relatively little energy to transport the gas to your site.

If you are interested in the environmental impact of your building compared to other buildings, choose *source energy*. If you would rather know what amount of energy is used once the energy gets to your site, choose *site energy*. If you purchase renewable energy, then the conversion from site to source energy won't make sense for you, since it is based on average fossil fuel power plant efficiency, so choose site energy.

What to do with the Benchmarking Results?

Whatever benchmarking method you use, knowing how you compare to your peers is a good motivator for energy efficiency. Benchmarking over the years is one way to track building performance and identify buildings with significant potential for improvement.

Benchmarking Resources

Energy Star Portfolio Manager available at **www.energystar.gov/benchmark**

Cal-Arch Benchmarking Tool available at **http://poet.lbl.gov/cal-arch/**

Lawrence Berkeley National Laboratory Cleanroom Benchmarking:
http://ateam.lbl.gov/cleanroom/benchmarking/

Oak Ridge National Laboratory Benchmarking Spreadsheets for Office Buildings:

http://eber.ed.ornl.gov/commercialproducts/cbenchmk.htm

Utility Tracking

What gets measured gets managed. In a recent study, 9 out of 10 facility managers did not look at utility bill data on a regular basis and did not know how well their facility's performance was maintained.

While benchmarking your building compares your utility consumption to other buildings, tracking utility use is the first step in understanding your building's consumption patterns. Tracking monthly bills or more frequent metered data is an essential part of monitoring building performance over time and can help spot emerging problems before they cause occupant discomfort or premature equipment failure. Utility tracking and troubleshooting are key elements in insuring long-term system performance. The most costly operational problems often do not affect comfort, so tracking can be the only way that these problems will be recognized.

What Should You Look For in Utility Data?

Compare the curves for different years.

Comparing average daily consumption trends with those for previous years can provide interesting insights. If the operating patterns and loads for the building do not vary much from year to year, then the average daily consumption pattern should be fairly consistent. Of course, there will be minor differences between years due to variations in weather, but significant variations may be an indicator of a problem.

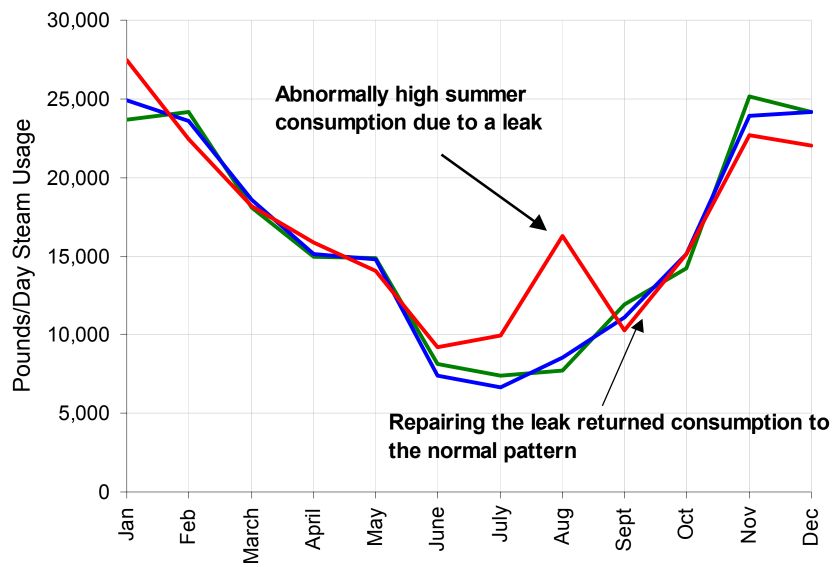

Figure 4: Average Daily Consumption Monitored Over Three Years.

Figure 4 illustrates the consumption of a building over a three-year time frame. Reviewing the utility bills on an ongoing basis enabled the facility manager to quickly spot a rise in consumption in July that was confirmed in August. Troubleshooting in the heating system revealed a leak in the steam to water heat exchanger. The leak was repaired in August and the energy use returned to normal in September. This type of analysis can lead to significant avoided costs.

Look at the peaks and valleys of the curves.

Often the peaks and valleys of the curves indicate if there are energy efficiency opportunities at a facility. Figure 5, an office building in the Pacific Northwest, shows excessively high baseline gas consumption. On a summer day, the building uses almost 50% of the gas that it uses on the coldest winter day, even though no heating is required in the summer. There are several legitimate reasons for gas usage in the winter, such as for cooking in a large kitchen or cafeteria or gas used for a process or production load. In this situation, high reheat loads were the cause of the problem. The situation was rectified by adjusting the minimum air flow to match the occupant load, reprogramming the terminal equipment, and implementing zone level scheduling.

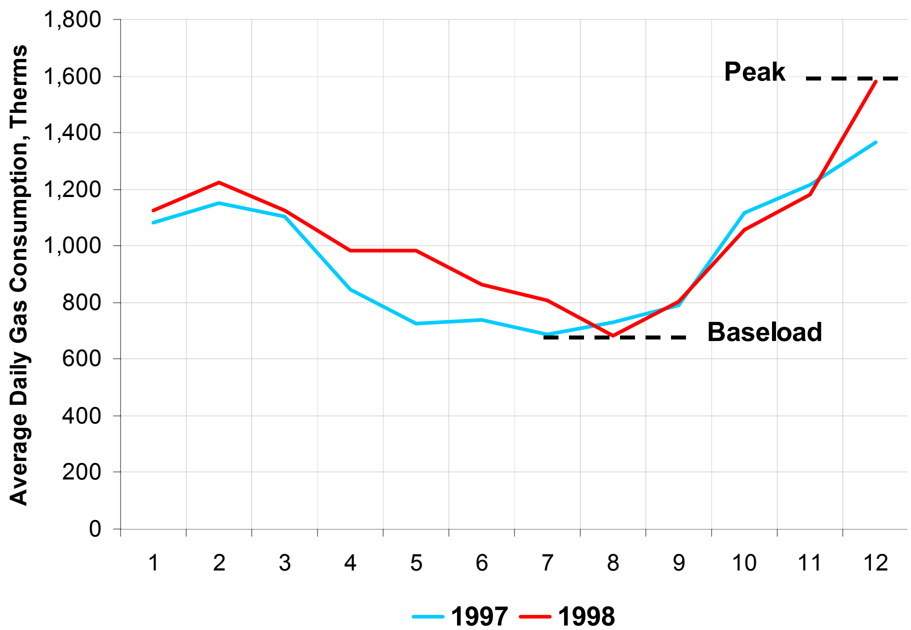

Figure 5: Identifying Base Load and Peak Demand

More sophisticated techniques for creating a baseline energy performance to compare and track ongoing performance are described in the *International Performance Measurement and Verification Protocol* [9].

[9] IPMVP 2001. IPMVP Committee, *International Performance Measurement & Verification Protocol: Concepts and Options for Determining Energy and Water Savings*, Vol. 1, U.S. Dept. of Energy, DOE/GO-102001-1187, 86 pp., January. Available at www.ipmvp.org

How Can Utility Tracking Be Automated?

Energy Information Systems (EIS) are tools that automate utility tracking and provide several other useful management features. Automating this process will help you monitor energy use for multiple sites or allow you to track more frequent data intervals (daily or even hourly). Even better, with automated tracking, there's no need to wait for the monthly bill.

What is an Energy Information System and how can it help me improve system performance?

An EIS takes utility bill tracking to the next level in the following ways:

- **Time saving**: EIS automatically gather hourly or daily updates of consumption data, which saves time and provides greater detail compared to utility bill tracking.
- **Immediate feedback**: Facility operators have the ability to check the impact of a change in operating strategy the day after it is made without having to wait until the next month's utility bill arrives. Facility operators have the ability to visualize the information in different ways. Instead of noting monthly variations in energy, they can spot problems daily and see the effect of an improvement immediately.
- **Gather additional data**: Some EIS gather more than just consumption data, such as chiller power and space temperature.
- **View data over the Internet**: Some EIS allow the user to view utility data over the Internet. More advanced EIS also allow viewing and controlling other parameters such as setpoints over the Internet. Facility managers responsible for many sites can work on multiple buildings from a single site.

In the past, EIS were mainly used in custom applications to track energy for campuses of buildings. These applications were applied internally to a campus network, not over the Internet. With advancements in technology, web-based EIS are becoming more prevalent in the market. Web-based EIS allow users on-site and remotely to view data and identify problems.

A recent report on the currently available web-based EIS divided them into four categories.[10] As a building owner or manager, these categories may help in evaluating which system is most appropriate.

1 **Utility Information Systems (Utility-EIS):** *Automates the process of gathering utility data for a single building. A* Utility-EIS gathers whole-building data from dedicated meters or from an EMCS in hourly or 15-minute intervals. It archives the data for reference.

2 **Demand Response Systems (DRS):** *Best as part of a load reduction program to help streamline the data collection process.* Web-based communications between utilities and customers allow credit for reductions in demand when system loads are high. These features have been incorporated into a number of EIS.

3 **The Enterprise Energy Management (EEM):** *Best for owners or managers of multiple facilities who want to compare energy consumption per square foot and identify the most energy-intensive facilities.* The EEM EIS includes the features of the Utility-EIS plus the ability to track parameters for several buildings.

4 **Web-based Energy Management and Control Systems (Web-EMCS):** *Best for monitoring and control of systems over the Internet, integrating data storage, visualization, and control of different building control systems (i.e., HVAC, lighting, security, utility meters)?* Web-EMCS allows you to monitor and control multiple system vendors using a gateway that can translate different vendor's protocols into a single user interface. This data can be uploaded to a remote server for energy managers, operators, or even third-party data analysts to view and analyze. The Web-EMCS type of EIS allows you to add points such as chiller power, space temperature, and VFD speed. With these points, you can more closely track your building operations via the Internet.

The table below is based on a study that includes approximately half of the EIS available on the market or in development. A wealth of additional information about these tools is available in the full report.

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[10] Montegi, N. and M.A. Piette, Web-based Energy Information Systems for Large Commercial Buildings. Report for the California Energy Commission, Public Interest Energy Research Program. Available at http://buildings.lbl.gov/hpcbs/Element_5/02_E5_P2_2_1.html

Table 1: EIS and Vendor Information

Software	Vendor / Developer	EIS Types: Utility-EIS	EEM	DRS	Web-EMCS
AMICOS	Southern California Edison	✓			
AES-IntelliNet	AES Corporation	✓			
Enerlink.net	SCT Corporation	✓			
Demand Exchange	Apogee Interactive	✓		✓	
Readmeter/Loadcontrol	Cannon Technologies	✓		✓	
EP Web	ELutions	✓		✓	
Energy Profiler Online	ABB	✓	✓	✓	
PLISEM	Plurimi			✓	
energy1st	Stonewater Software	✓		✓	
Load Profiler	Automated Energy	✓	✓		
UtilityVison	CMS Viron	✓	✓	✓	
EEM Suite	Silicon Energy	✓	✓	✓	✓
EnterpriseOne	Circadian Information Systems	✓	✓		✓
Intelligent Use of Energy	WebGen Systems	✓		✓	✓

Energy Use Tracking Resources

Using Utility Bills and Average Daily Energy Consumption to Target Commissioning Efforts and Track Building Performance. David Sellers. Proceedings of the International Conference on Existing Building Operations 2001. Available at **www.peci.org/papers/utilbills.pdf**

Web-based Energy Information Systems for Large Commercial Buildings. Naoya Motegi and Mary Ann Piette Report for the California Energy Commission, Public Interest Energy Research Program. Available at: **http://buildings.lbl.gov/hpcbs/Element_5/02_E5_P2_2_1.html**

Trend Analysis

Experienced retrocommissioning providers, facilities engineers, and operators all know that most buildings will "tell you" where their problems are if you only spend a little time looking for them. The data handling capabilities of DDC systems provide one powerful tool for "listening" to your building. If your DDC system is not well-equipped for trending, portable data loggers can be used to provide short-term trending for analysis. But simply gathering data does not ensure lasting building performance. Knowing how to interpret that data and following up with troubleshooting are equally important. This section discusses trending techniques and some tools that help automate trend analysis.

Identifying Problems Using Trending

Whether you have a known problem to troubleshoot or hidden energy waste, trending can help identify and improve building performance. Here are two examples of problems that can be detected through a quick trend analysis.

Hunting decreases valve and damper life, increases maintenance problems, and often leads to poor comfort control. In Figure 6, a hunting problem is identified during the night hours. Without trending at the proper frequency, this problem may not have been uncovered.

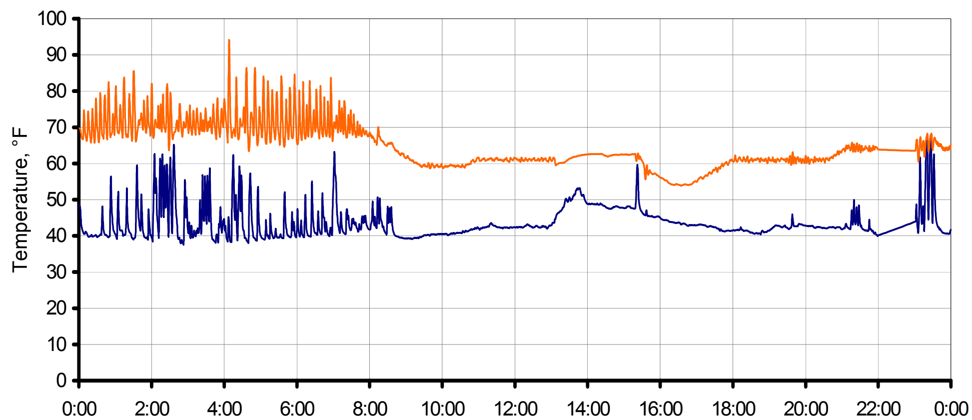

Figure 6: Identifying Hunting Through Trending
Trending at this building uncovered a hunting problem during the night, a problem that can decrease valve life and lead to comfort problems.

To understand if your system's VAV operation is working correctly, simply plot the VFD speed over time. A flat profile, like in Figure 7 below, corresponds to improper VAV operation. The supply fan speed is perfectly flat during the day, which corresponds to a manually operated VFD in override mode. The exhaust fan speed only varies slightly throughout the day, which could indicate a problem with terminal unit flow settings.

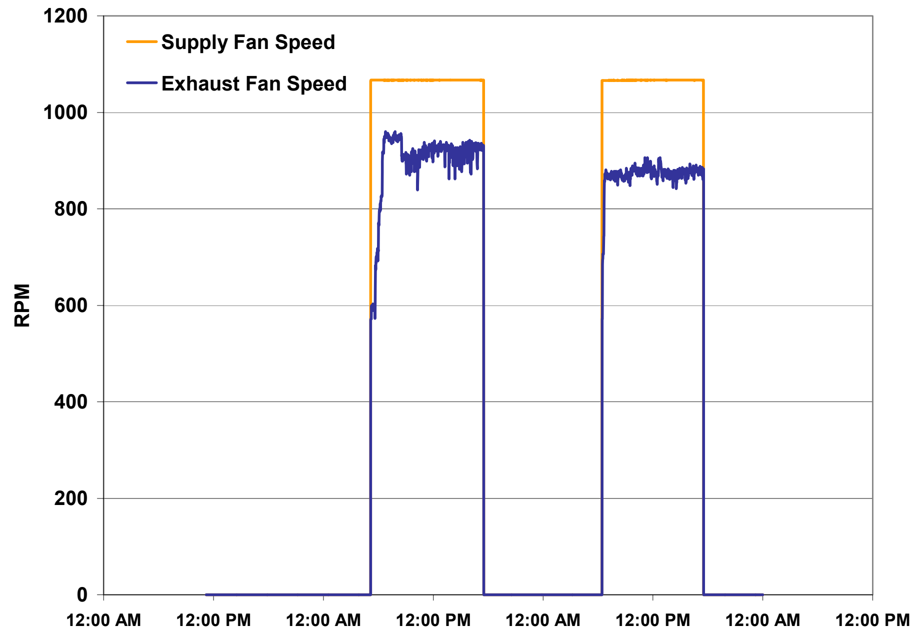

Figure 7: Identifying VFD Operation Through Trending
Trending at this building revealed improper VAV operation. The flat supply fan speed during the day indicates that the VFD is in override mode.

What trending capabilities should my system have?

If your system doesn't have enough memory to trend and archive data in a way that doesn't slow the control functions of your DDC system, then trending will be a difficult process. Defining a good specification for control system trend capabilities is appropriate for new construction or controls retrofits. See *Energy Management Systems: A Practical Guide*, Appendix A for specific language to include in the relevant controls sections of a specification (a link to this Guide is listed under Resources on page 36).

It is critical to understand how your DDC system handles trend data. Will data automatically download to the hard drive when the controller memory storage is full? One trick to avoid degradation in system performance from network traffic due to trending is to schedule your downloading from the controller to the central computer in the middle of the night or when the system fields fewer demands from other sources. Sampling at higher frequencies will uncover unstable control – but make sure that your control system can handle the rate of data transfer involved with higher sampling rates.

Where do I begin?

For an existing system, the control vendor may need to be contacted if the trending capabilities and their use are not clear. Becoming familiar with the process of setting up trends and manipulating data is half the battle. Read the control system manual, call the vendor for help, set up a few trends, and then look at a small amount of data to get familiar with the process. Most importantly, start small. Jumping into the analysis of 50 different points over three months is an overwhelming task that can be a recipe for failure if you are not already comfortable with the process.

The first step in setting up trends on your DDC system is to write out a trending plan that indicates the points to trend, sampling rate, and plan for analyzing the data. Trending can be prioritized in the following order:

1. Systems with current comfort or operational problems.
2. Systems suspected of faulty operation.
3. Areas that tend to have problems for everyone, such as economizers and variable speed drives.
4. Systems that consume large amounts of energy.
5. Systems that have recently been repaired or retrofitted and need verification.

After understanding your trending priorities, decide what parameters to trend for your particular needs. In general, think about what points you require to get the whole picture. Table 2 provides examples of points to trend in order to look into particular system issues. Creating a table like this for your facility can be a valuable way to organize your trending plan.

Table 2: Excerpt from a Trending and Analysis Plan

Issue or Equipment	Points to Trend	Sampling Interval	Analysis Summary
Unnecessary equipment operation	Change of value (COV), another indicator or an ON condition Time-series also works well.	COV or time-series 15 min.	Make sure HVAC is not unnecessarily on outside of occupancy periods. Verify that lighting ON times match HVAC.
Chiller efficiency	Primary chilled water and condenser flow (or values in TAB or start-up report), entering and leaving chilled water temp and chiller kW (or current). For reference, also condenser water supply and return temps.	15 min.	Calculate the kW/ton of cooling. Plot kW/ton vs. chiller % load as a benchmark. During similar weather next season, see if the kW/ton remains the same or is degrading (possibly indicating fouling). Compare to manufacturer's kW/ton.
Terminal unit	Zone temperature, heating coil valve position and command, air cfm or damper position, cfm setpoint. The outside temp and duct static pressure may also need to be trended.	2 min.	Plot with two Y-axes for resolution. Observe that the zone temperature remains within 1°F of the deadband, the cfm is not over or undershooting its setpoint or hunting, the heating valve is not hunting, and the cfm is at minimum before the heating valve opens.

The sampling interval for time-series data needs to be carefully considered – the sampling rate depends on the purpose of the trend and the memory limitations of the DDC system. For trending points with a slow rate of significant change, such as space or outside air temperatures, a 15-minute sampling rate is adequate. If the purpose of the trend is to investigate possible hunting of actuators or short cycling of equipment, the ideal sampling rate is about two minutes. The trend for a variable speed drive that is hunting at a 10-minute cycle rate can look like a flat, stable line if you are sampling every 10 minutes!

The default trending mode in many DDC systems continuously trends all points but keeps only the data for the last 24 hours. The 24-hour point history can be viewed graphically - a valuable tool when spot-checking individual points.

Viewing trend data using the existing DDC system functions is easier than exporting the data to another program, although for most systems, internal DDC graphing options are limited. For instance, a control system's internal graphing features may not allow multiple points to be viewed with two different axes or graph one variable against the other. In this case, you have to export the data to a spreadsheet program like Microsoft Excel.

Analyzing the Data: What to Look for

- What should be happening to different points at different times of the day?
- Review the sequence of operations to understand the intended operation of the system.
- After looking at trend data for systems with known or suspected problems, look for the common issues listed in Table 2. Fixing these problems can save you both energy and maintenance costs.

By analyzing the trend data consistently, such as every three months or so, operators and building managers can spot problems before operating cost waste accumulates.

Scaling Your Data

Don't forget about scaling factors when you are looking at trends. An out of control duct static pressure swinging half an inch w.c. around set point may "disappear" when plotted on the same axis as discharge temperature with the axis scale set at 0-100. In a spreadsheet program, you can make two axes to accommodate different ranges of values.

Automating Trending with Diagnostic Tools

No time to pour over trends for hours? The next generation of trend analysis called automated diagnostics was created to save time in pinpointing a problem. Automated diagnostics means using computer software to analyze trend data, detect problems, and even suggest solutions. These tools take enormous amounts of data and extract information that you can act upon.

Some diagnostic tools can tell when the problem occurred, at which piece of equipment, and for how long. A few of the tools quantify the energy waste related to specific problems, allowing prioritization of maintenance tasks.

Examples of problems that can be detected through automated diagnostic tools:

- Excess cycling
- Simultaneous heating and cooling
- Chiller efficiency degradation
- Struggling pumps, valves
- Lack of economizer cooling
- Leaking cooling and heating coils
- Unstable or oscillating control

Diagnostic tools have varying degrees of automation in the following categories:

1. **Data acquisition:** *Does the diagnostic tool automatically gather the data for analysis?* Moving data from your control system into a diagnostic tool is a critical step that generally requires set-up by an experienced user.

2. **Archiving and pre-processing:** *Does the diagnostic tool archive the trend data for future use? How does the tool deal with erroneous data?* To streamline the analysis of historical data, some tools archive the trend data they collect. Since EMS data have the potential for missing and erroneous values, some tools pre-process the data to synchronize timestamps and validate data (identify missing and/or bad data).

3. **Detection:** *How does the tool help the operator to detect problems?* Manual diagnostic tools help users detect problems by extracting useful information from raw trend data. These tools require that users have the knowledge to identify problems using the plots and information automatically generated by the tool. Automated detection requires less user analysis of data since the tool automatically reports problems. Automated detection relies on expert rules or modeling to detect deviations from expected operation. Detection is the heart of diagnostic tools.

4. **Diagnosis:** *After detecting a problem, does the tool help diagnose the problem?* Some tools automatically supply a list of possible causes and appropriate remedies for the problem. Still, diagnosing the cause of the problem is an educated "guess" by the computer software – finding the real source requires an experienced and informed building operator.

Automated diagnostic tools are relatively new to the commercial buildings market. Different tools have filled the need for automated diagnostics in different ways. Below are two example tools – ENFORMA and PACRAT.

ENFORMA

The ENFORMA software has been on the market since 1996. ENFORMA should be used for periodic tracking and recommissioning efforts, but not ongoing diagnostics. The ENFORMA software automatically creates a metering plan, determines the sensors needed and programs the dataloggers to get time-synchronized building data. Data can also be imported from control points on your existing DDC System.

From this data, ENFORMA automatically generates graphs to compare against their standard reference plots. The reference plots help the user visualize correct and incorrect operation. The software doesn't detect problems in the measured data but relies on the user to interpret the data. Additionally, the user can filter the data to visualize appropriate time periods.

Figure 8 displays an ENFORMA diagnostic plot. The top graph uses the actual data that is filtered by the tool to show only operating hours. The bottom graph ("reference plot") shows what proper system operation looks like. The user can view other reference plots to understand what other operating conditions look like (economizer not operating, no outside air, economizer always open). In this case, the actual data tracks the reference data well, indicating that the economizer is operating efficiently.

ENFORMA has been commercially available longer than any other diagnostic tool and is the least expensive tool at $495. For more information, go to: http://boulder.archenergy.com/enforma/

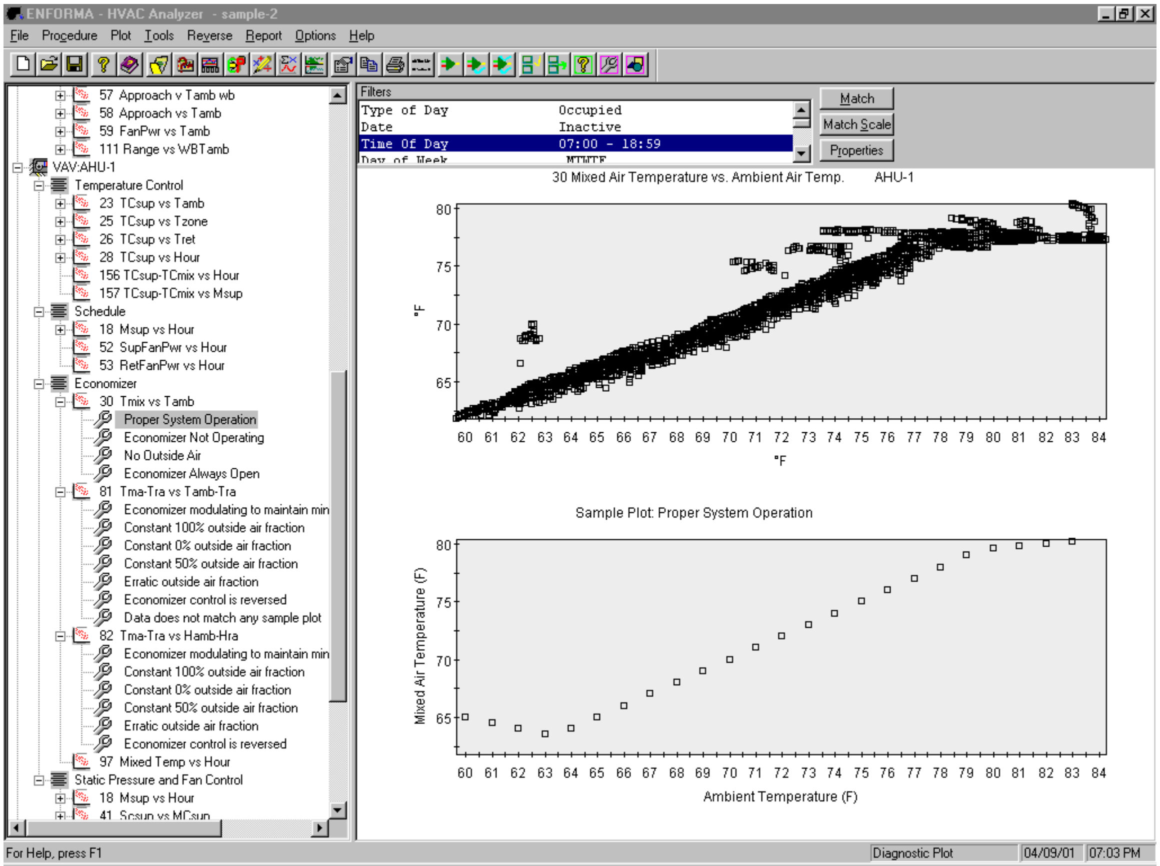

Figure 8: ENFORMA Economizer Plot with Example Reference Plot

PACRAT

The Performance and Continuous Re-Commissioning Analysis Tool (PACRAT) is a software package designed to automate HVAC system diagnostics, provide a data visualization platform, and automate measurement and verification tasks. PACRAT has been commercially available since 1999 and can be used as an ongoing diagnostic tool. The tool gathers and archives data, processes the data through its diagnostic algorithms, and outputs problems and recommended solutions.

PACRAT's data management routine has both service and software components. In a typical installation, data is gathered from client machines and sent over the Internet to a remote PACRAT server. Data is copied from trend files set up in the existing EMS and converted into a database using a gateway programmed specifically for each control vendor. The PACRAT server processes the data, which is analyzed for accuracy and diagnostic sensitivity by PACRAT service providers. The diagnostic results are made available to the user over the Internet.

Figure 9 shows a typical PACRAT anomaly form, reporting problems detected by the software. Note that "Possible Causes" and "Associated Resolution" is provided to help guide the troubleshooting process. The interface shows the date the issue occurred and is linked to a graph showing data supporting the issue. The "$ Waste" shows calculated energy waste based on the anomaly date range and the utility rate schedule.

PACRAT's higher cost ($10,000-$30,000, depending on the number of points) reflects the service component and the automated detection of problems. For more information, go to: www.facilitydynamics.com/pacrat.html

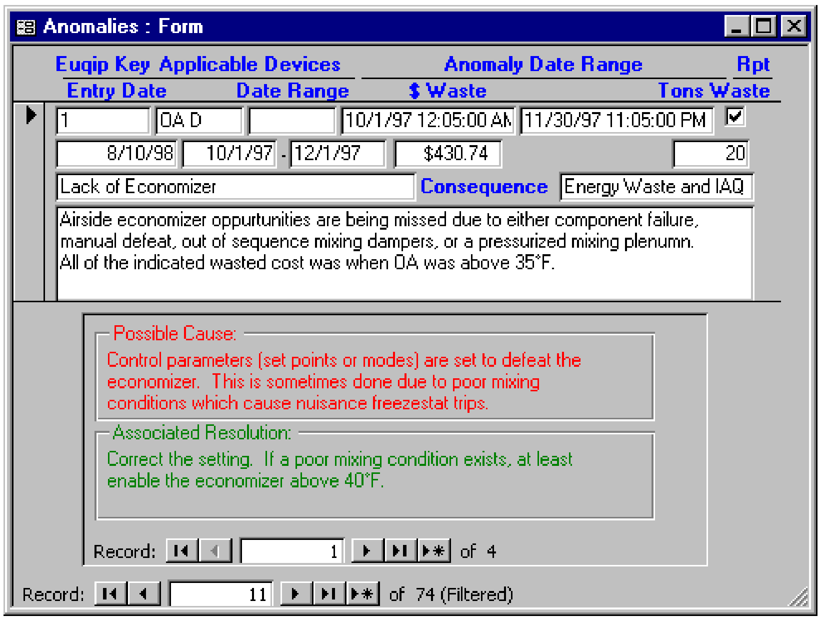

Figure 9: PACRAT Anomaly Form

Trending and Automated Diagnostic Resources

Energy Management Systems: A Practical Guide, PECI O&M Best Practices Series. Available at **www.peci.org/om/ems.pdf**

Portable Dataloggers: Diagnostic Tools for Energy-Efficient Building Operation, PECI O&M Best Practices Series. Available at **www.peci.org/om/datalog.pdf**

Installation of Data Loggers. David Sellers. January 2003, Heating/Piping/Air Conditioning Engineering (HPAC). Available for purchase at www.hpac.com

Datalogger Operation Tips. David Sellers. February 2003, Heating/Piping/Air Conditioning Engineering (HPAC). Available for purchase at **www.hpac.com**

Comparison of Emerging Diagnostic Tools for Large Commercial HVAC Systems. Hannah Friedman and Mary Ann Piette. National Conference on Building Commissioning, 2001. Available at **www.peci.org/papers/diagtools2.pdf**

Recommissioning

Why Should I Recommission?

Recommissioning is the process of commissioning existing buildings that have already been commissioned sometime in the past. Building owners and managers that carefully document their building systems, provide good training for facility operators, and perform ongoing benchmarking, utility tracking, and trending activities may not need to recommission their facilities very often, if at all.

But in the real world, these practices are rare. The studies on persistence showed that all buildings had the potential for improved operations, even only two years after commissioning occurred. When recommissioning, make sure to draw upon your past commissioning effort. Cost-effective recommissioning takes advantage of previous documentation when comparing current and past performance.

When Do I Re-commission?

When recommissioning is needed depends largely on how well O&M strategies have been implemented and, as a result, how well the facility still meets the needs of the occupants. If you answer 'yes' to two or more of the following questions, you should consider a recommissioning process at your facility:

- Is there an unjustified increase in energy use? Is energy use more than 10% higher than previous years?
- Have comfort complaints increased compared to previous months or years?
- Has nighttime energy use increased?
- Do you know about problems but don't have the time or in-house expertise to fix them?
- Has control programming been modified or overridden to provide a quick fix to a problem?
- Are there frequent equipment or component failures?
- Have there been significant tenant improvement projects (build-outs)?

Who Should Recommission the Facility?

1. **Commissioning Provider Consultant:** When recommissioning a facility with known problems, hiring a commissioning provider may be the best choice. Even if you can reallocate resources to do the recommissioning in-house, a "fresh set of eyes" can do wonders to solve nagging problems. The operations staff should work as closely with the commissioning provider as time permits – the troubleshooting techniques and systems knowledge gained is valuable for building operations staff after the recommissioning effort is complete. With a good understanding of the recommissioning

process, the in-house operations staff may be well prepared to perform recommissioning the next time its needed.

2 **In-house commissioning:** In cases where the operations staff has the time and resources to focus on recommissioning, the staff can perform recommissioning without hiring a consultant. For staff that are working at the building every day, this testing and troubleshooting experience improves their knowledge of the systems.

Recommissioning Resources

A Practical Guide for Commissioning Existing Buildings. PECI and Oak Ridge National Laboratory, 1999. Available at **www.peci.org/cx/weblinks.html**

Retrocommissioning on Demand: Using Energy Information to Screen Opportunities. Lynn Fryer. National Conference on Building Commissioning, 2002.

Energy-Efficient Operation of Commercial Buildings: Redefining the Energy Manager's Job. Peter Herzog. McGraw-Hill, 1997.

Continuous Commissioning®

Continuous commissioning is an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities.

The Energy Systems Laboratory (ESL) at Texas A&M University has employed the *Continuous Commissioning®* process in more than 130 large buildings over the last ten years (Liu, Claridge, and Turner, 2002). *Continuous Commissioning®* involves many of the same planning and investigation procedures as retrocommissioning. Like retrocommissioning, continuous commissioning activities consist of a systematic way of identifying and correcting building system problems and optimizing system performance in existing buildings. The main difference is that continuous commissioning more rigorously addresses the issue of persistence than retrocommissioning. In other words, continuous commissioning activities are ongoing, rather than an event that occurs once or twice in the lifetime of the building. This continued attention helps ensure that the savings from commissioning do not degrade over time.

Continuous Commissioning® (CC) ensures the persistence of building performance through the following tasks– see the details in the CC Guidebook:

- **Document CC activities** including sequences of operation, the reasons behind these procedures, and documentation of current building performance.
- **Measure energy and maintenance cost savings** to justify the CC activities, preferably following the International Performance Measurement and Verification Protocol.
- **Train operating and maintenance staff** to ensure a good understanding of the reasons behind the changes made during CC. Staff should be a part of the commissioning team to propose and help implement the changes.
- **Continuously measure energy consumption** as the first line of defense against declining performance.
- **Obtain ongoing assistance from CC engineers** before undoing implemented CC measures. The experienced continuous commissioning provider should provide follow-up phone consultation to the operating staff as needed, supplemented by site visits. If the CC provider can remotely log into the EMS, they can check system operation quarterly.

Continuous Commissioning Resource

Continuous Commissioning®Guidebook: Maximizing Building Energy Efficiency and Comfort. Liu, Mingsheng, Claridge, David E. and Turner, W. Dan, , Federal Energy Management Program, U.S. Dept. of Energy, 144 pp., 2002. For more information: **http://esl.tamu.edu/cc/**

Going Forward with Persistence

Maintaining the benefits of commissioning is a goal that takes some planning and documentation, but most importantly, a commitment on the part of the facilities staff and management. In many ways, a thorough commissioning process that documents how the systems are supposed to run is the hard part. After investing all that time and money into the initial commissioning process - including design phase commissioning, the extra effort to provide training, track performance, and re-commission as necessary can become a routine part of your ongoing preventative maintenance program.

Glossary

In order to understand the commissioning process it is important to learn the terminology. Much of the commissioning terminology has been developed in the ongoing attempt of commissioning providers around the country to standardize the process, as well through 1as the development of commissioning guidelines by the American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE). This guideline provides definitions of the most common commissioning terms.

Benchmarking

Benchmarking is a method for tracking building or equipment performance against a previously determined measurement, standard, or criteria of excellence.

Commissioning

Commissioning is a systematic quality assurance process that helps prevent problems from arising by evaluating each of a building's systems, individually and as they interact. This is achieved ideally by documenting owner's project requirements beginning in the pre-design phase; continuing through design, with reviews of design and contract documents; and following through the construction and warranty period with actual verification through review, testing and documentation of performance. Through early detection of a wide range of problems, commissioning has been proven to reduce operating costs, tenant complaints, indoor air quality problems, and liability and tenant turnover costs.

Continuous Commissioning

Continuous commissioning is an ongoing process to resolve operating problems, improve comfort, optimize energy use and identify retrofits for existing commercial and institutional buildings and central plant facilities.

Design Phase Commissioning

The goal of commissioning during the design phase is to ensure that the efficiency and intended operation for the building systems are included in the final design. The commissioning tasks during this phase are: compiling and review design intent documents (owner's project requirements and their related acceptance criteria), incorporating commissioning into the bid specifications, and reviewing the design documents.

Functional Testing

Tests that evaluate the dynamic function and operation of equipment and systems using manual (direct observation) or monitoring methods. Functional testing is the assessment of the system's (rather than just component's) ability to perform within the parameters set up in the Basis of Design. Systems are tested under various modes, such as during low cooling or heating loads, high loads, component failures, unoccupied, varying outside air temperatures, fire alarm, power failure, etc. The systems are run through all the control system's sequences of operation to determine whether they respond as the sequences state. Functional tests are performed after construction checklists are complete.

Design Intent (also referred to as Owner's Project Requirements)

A document that provides the owner's vision for the planned facility and expectations for how it will be used and operated. It also provides a detailed explanation of the rationale behind the ideas, concepts and criteria that are defined by the owner to be important and to be tracked through design and construction. These concise concepts are likely to originate from the owner's program. The requirements may be written by the owner, the commissioning provider, or the design team in consultation with the owner. The Owner's Project Requirements remain relatively fixed from their initial development unless budget or other factors require a modification.

Recommissioning

Recommissioning is the process of commissioning existing buildings that have previously been commissioned. Recommissioning is similar to retrocommissioning except that efforts may be directed based on the original commissioning results. Functional tests and trending plans from commissioning may be used to streamline the recommissioning process.

Retrocommissioning

Retrocommissioning is the process of commissioning existing buildings that have not previously been commissioned. Retrocommissioning applies a systematic investigation process for improving and optimizing a building's operation and maintenance. The process is intended not only to optimize how equipment and systems operate, but also to optimize how the systems function together. Although retrocommissioning may result in recommendations for further capital improvements, the focus is on fixing existing system problems and obtaining energy and other cost savings for the owner.

California Energy Commission
Public Interest Energy Research Program

HPCBS # E5P2.2T5a2

HPCBS

High Performance Commercial Building Systems

Persistence of Savings Obtained from Continuous Commissioning SM

Element 5. Integrated Commissioning and Diagnostics
Project 2.2 - Monitoring and Commissioning of Existing Buildings
Task 2.2.5 - Investigate the persistence of the benefits obtained from different types of commissioning and continuous commissionings

Dan Turner, David Claridge, Song Deng, and Soolyeon Cho
Energy Systems Laboratory, Texas A&M University
Tom Hagge, Charles Darnell, Jr., Homer Bruner, Jr.
Physical Plant, Texas A&M University
Mingsheng Liu
University of Nebraska – Omaha

May, 2001

Acknowledgement

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Persistence of Savings Obtained from Continuous Commissioning SM

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Synopsis

The persistence project is a study which investigates the savings in energy consumption of ten buildings that were commissioned between 1996 and 1997 by the Continuous Commissioning (CC^{SM}) group at the Energy Systems Laboratory (ESL) at Texas A&M University. All buildings selected for the study are on the Texas A&M campus, and none received major capital retrofits. This study determined how much energy and dollars the commissioned buildings have saved and how persistently the savings have been maintained after CC activities were completed.

The savings results have been calculated from hourly monitored thermal and electrical data by using E-Model, a program for data processing, graphing, and modeling energy consumption data. The models before CC were used as the baseline. As a whole, chilled water and electric savings have degraded a little over time, and hot water savings are about the same. Factors that affect energy use such as Energy Management Control System (EMCS) settings, are discussed in this paper. The EMCS settings are presented as pre-CC, post-CC, and current control schemes. In the overall study, chilled water savings have been degraded in the rate of 2.67% per year, electric savings decreased 0.67% per year, and hot water savings have stayed about the same since CC. Savings results averaged during the last four years are 40% for chilled water, 62% for hot water, and 11% for electricity. The total savings for the 10 buildings are $4,255,000. For all 10 buildings, as a whole, savings obtained from Continuous Commissioning have generally persisted since the Continuous Commissioning was completed.

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Introduction

The investigation of the persistence of savings obtained from Continuous Commissioning (CC^{SM}) was initiated to see if the buildings, which have been commissioned at least three years, are still being operated as commissioned. The approach used was to review the CC reports, determine the EMCS settings from the commissioning, determine the current EMCS settings from the controls system and then visit the buildings to verify the current building operation. If any controls were in manual operation, that was also noted.

Continuous Commissioning was started in 1993 by the Energy Systems Laboratory (ESL) and was initially funded by the Texas LoanSTAR program. CC began on the Texas A&M University campus during the summer of 1996. The implementation of CC on the Texas A&M campus and overall results of this program have been reported elsewhere (Claridge et al. 2000a and 2000b). The ESL had nine months of baseline energy consumption data from a building energy information system prior to the onset of commissioning. Ten buildings commissioned in 1996 and 1997 were investigated in this study to determine persistence. These 10 buildings had fairly complete building energy data, from which the annual savings could be determined.

On the Texas A&M University campus, like many campuses, there are a number of different groups with responsibility for maintaining the buildings. Area maintenance has the day-to-day responsibility for maintaining occupant comfort. The Energy Office has overall responsibility for the controls system and handles most of the central controls settings. The campus EMCS is a Siemens Apogee^{TM} system, and Siemens technicians have access to the buildings' controls systems, while working under the Energy Office. The ESL engineers and technicians work with all these entities during the CC process and also assist with troubleshooting comfort problems in buildings. All groups thus have access to all the buildings in this study and have contributed to the results of the original CC effort.

Typical Continuous Commissioning measures include sensor calibration, implementation of hot deck and cold deck temperature reset, static pressure resets, control of outside air, use of economizer cycles, air and water balances, and changes in terminal box airflow settings. The focus of this investigation is not on these detailed field histories of each building but rather on the main energy management control system (EMCS) for pre, post, and existing control settings and on the CC reports.

Energy use data from energy monitoring equipment were used to determine savings after CC, and the data before CC were used as the baseline. The ten buildings were divided into two groups, one group which showed good persistence and the other which shows poorer persistence. The reasons for the deviations are discussed, and strategies for maintaining the benefits of Continuous Commissioning are recommended in this paper.

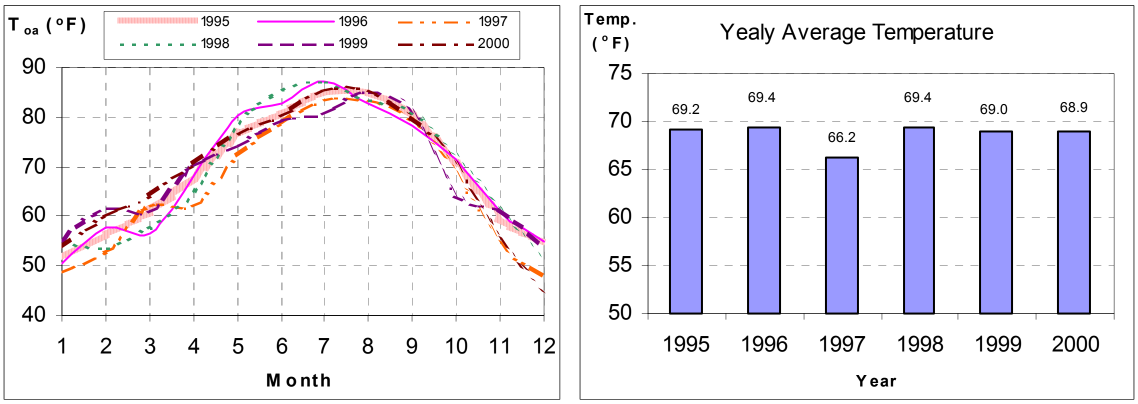
Procedure

The following is a description of the procedures that were followed in this study of persistence of savings obtained from Continuous Commissioning. First, the 10 buildings had to have at least three years history after CC. Second, the hourly monitored data set needed to be fairly complete with good baseline data and a well-documented CC report. Table 1 shows brief information for the 10 buildings.

Table 1: Information for 10 Texas A&M University buildings selected for the study.

No.	Building Name	Area (ft^2)	HVAC System Types	CC Period
1	Blocker	255,490	10 DDVAV AHUs & 2 100% OA units 2 SDCV AHUs & 1 Liebert unit	2 / 97 - 4 / 97
2	Eller O&M	180,316	4 DD-Dual Fan VAV AHUs 2 CV MZ Units	2 / 97 - 3 / 97
3	G.R.White Coliseum	177,838	13 CV AHUs 5 SDCV AHUs with reheat coil (Pneumatic)	5 / 97 - 7 / 97
4	Harrington Tower	130,844	1 - 200 hp DDVAV AHU 3 smaller SD AHUs for 1st floor	7 / 96 - 8 / 96
5	Kleberg Building	165,031	2 x 100 hp SDVAV AHUs 2 x 25 hp return air fans	4 / 96 - 7 / 96
6	Koldus Building	97,920	5 SDVAV AHUs 5 SDCV AHUs	3 / 97 - 4 / 97
7	Rich. Petroleum	113,700	7 SDVAV AHUs 2 SDCV AHUs	9 / 96 - 9 / 96
8	Vet Med Center Addition	114,666	5 SDVAV AHUs 4 out of 5 AHUs are 100% OA	10/ 96 - 11/ 96
9	Wehner CBA	192,001	6 DDVAV AHUs 3 SDVAV AHUs	11/ 96 - 12/ 96
10	Zachry Engr Center	258,600	12 DD-Dual Fan VAV AHUs 3 SDCV AHUs	12/ 96 - 3 / 97

Energy consumption for pre-CC and post-CC periods have been determined on a yearly basis. However, to compare the performance of all 10 buildings with the pre-CC baseline, it was decided to use weather data for a common year. After comparing the years 1995 through 2000, it was decided to use 1995 as the "normal" year. Figure A shows the annual and monthly average temperatures for 1995-2000 in College Station, TX. The year 1995 not only had an average temperature nearest to the average for the period, but also the average temperature for every month was within the extremes for that month as well.



(a) (b)

Figure A: College Station weather data during last six years.

CHW and HW energy consumption has been measured for each year, and three-parameter or four parameter change-point models of cooling and heating consumption have been determined as functions of ambient temperature by E-Model (Kissock et al., 1994), a program for data processing, graphing, and modeling energy consumption data. Basically, each building has five years of CHW and HW models, including the baseline model. The consumption was then normalized to 1995 weather by using the models for each year's data with the 1995 temperature data. There will be some differences between measured energy consumption and normalized energy consumption, but normalization removes variation due to weather differences. However, the measured electricity consumption data have been used since the buildings do not contain chillers and electricity consumption is only slightly affected by ambient temperature. The energy savings have been determined as the differences between the baseline consumption and the consumption for each year (all normalized to 1995 temperature data). Savings and trends have been investigated in the chronological order of pre-CC, post-CC, and current performance.

Savings after CC

As mentioned above, chilled water and hot water savings after CC were determined based on the 1995 weather data as the normal year, but electric savings were from actual data without weather normalization. Figure B shows the result of the savings for each building. All the ten buildings have reduced chilled water and hot water energy consumption since the CC activities, although the savings have degraded somewhat with time. For the electrical consumption, the Richardson Petroleum and the Wehner Buildings show negative savings of thirteen percent and seven percent, respectively.

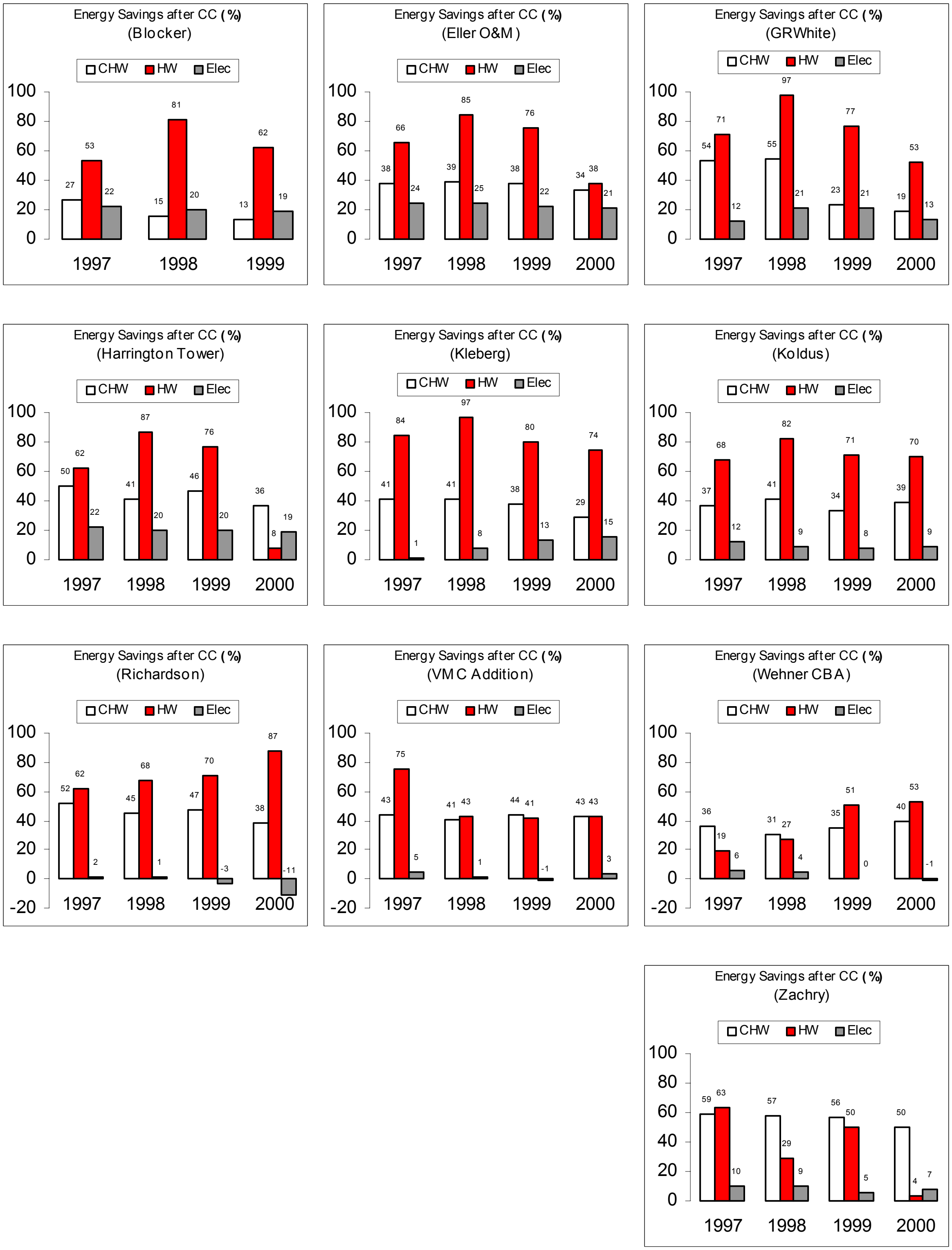
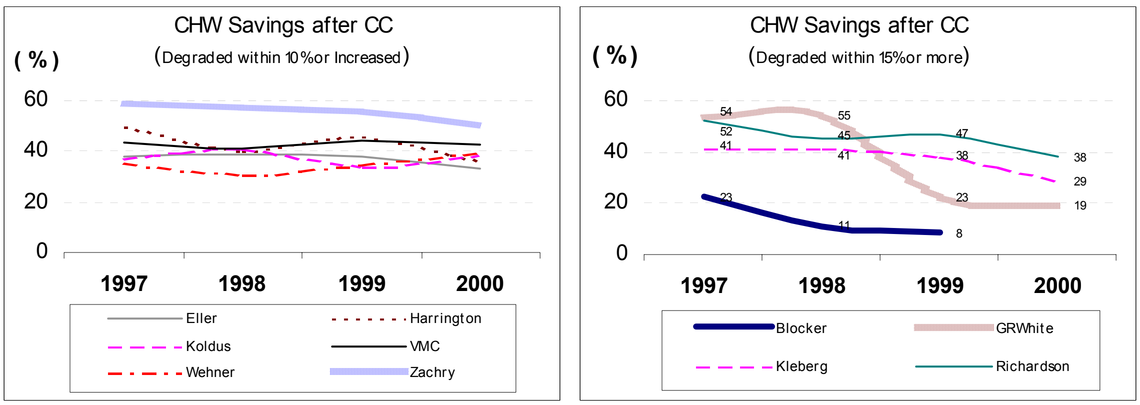


Figure B: Trends of energy savings results after CC activity for 10 buildings at Texas A&M University, College Station, TX.

Chilled Water Savings

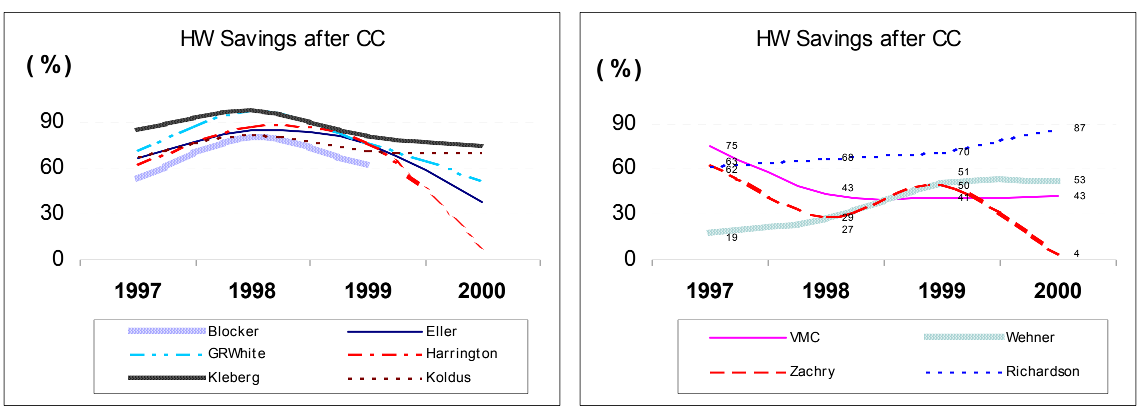
To see clearly the chilled water savings after CC, the ten buildings were divided into two groups, one for the buildings that show good persistence of savings (less than 10 % decrease during the 3~4 years after CC) and one for the buildings with significant degradation. Overall, chilled water savings average around 40% from the pre-CC baseline. Figure C(a) is the grouping of six buildings showing little degradation (or increased savings). Figure C(b) shows the four buildings with degraded performance.



(a) (b)

Figure C: Yearly CHW Energy Savings after CC Activity Based on pre-CC Energy Consumption Baseline.

Hot Water Savings



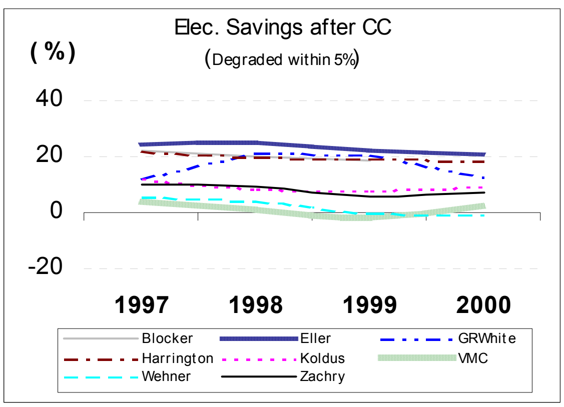
(a) (b)

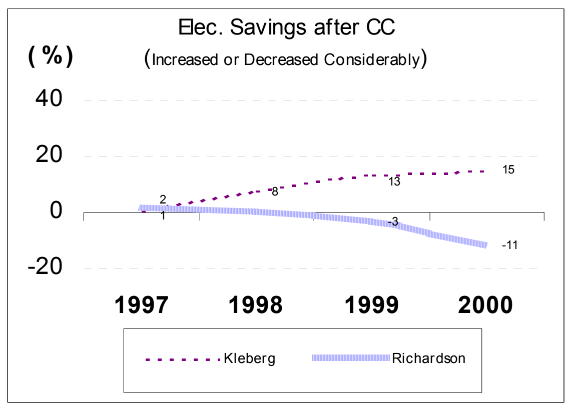
Figure D: Yearly HW Energy Savings after CC Activity Based on pre-CC Energy Consumption Baseline.

Hot water consumption has been significantly reduced since CC was performed, but the amount of the savings for each year fluctuates widely, making it difficult to determine annual trends. Figure D(a) shows the series of the six buildings with fairly consistent savings. Figure D(b) shows widely varying results for the HW savings. The buildings averaged hot water savings around 62 % after CC.

Electric Savings

Electric savings have been consistent for eight buildings after CC, as noted in Figure E(a), but two buildings display a wider range of variation, as noted in Figure E(b). One of these buildings shows increased savings over time after CC, and the other building (Richardson) has negative electrical savings overall.





(a) (b)

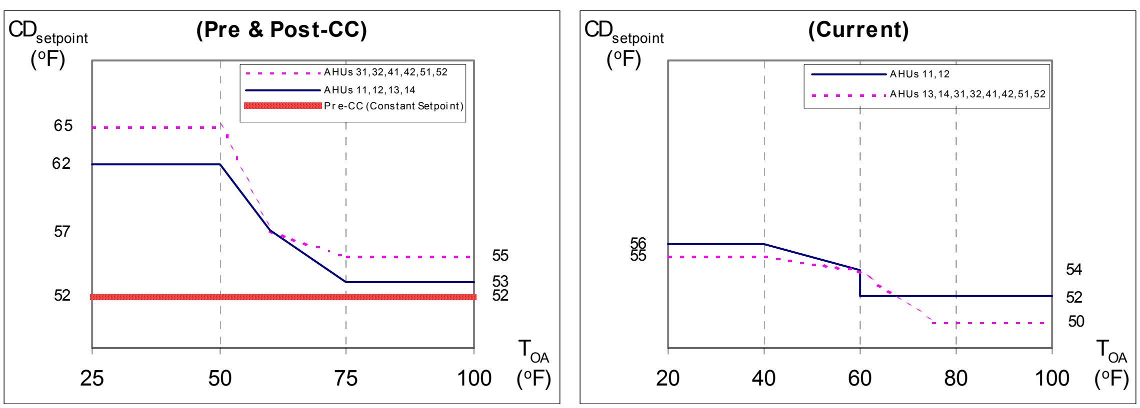
Figure E: Yearly Electric Energy Savings after CC Activity Based on pre-CC Energy Consumption Baseline.

Comparisons between Pre, Post, and Current EMCS Settings

Checking and optimizing Energy Management Control System (EMCS) settings are some of the most important parts of CC activities. All buildings are being controlled by a Direct Digital Control (DDC) system, which has been installed by Siemens^{TM}. Many local settings, including cold deck and hot deck temperatures, and static pressures, are not only controlled and set with the computer, but also surveyed and measured by CC engineers in the field during CC activities. According to the CC measures implemented between 1996 and 1997 and based on existing control settings, some reasons for the savings trends could be found. In this section only some typical buildings are selected to show why the savings are going down.

Cold Deck / Discharge Temperature Settings

Cold deck or cooling coil discharge temperature settings affect CHW consumption. The Blocker Building is selected among the 10 buildings, since this building shows typical EMCS set-point histories and a relatively large degradation of savings after CC. All buildings, except the Koldus Building, currently have different set points which demand more energy than those set during the CC. As shown in Figure F(a), the cold deck set points for 10 AHUs in the Blocker building had been constant at 52 F and then were reset during CC; however, the reset points are not the same as current settings, and the current settings require more cooling. The exact history as to when the cold deck settings were changed is not known, but it is likely that several reset processes could have occurred since CC completion.

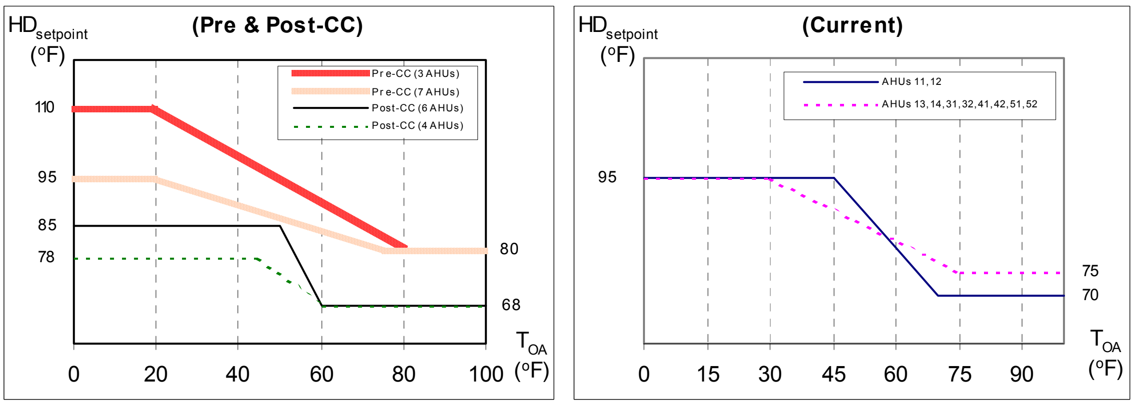


(a) (b)

Figure F: Comparison of pre-CC, post-CC, and current Cold Deck schedules in the Blocker Building.

Hot Deck Settings

Five out of the ten buildings have dual duct AHU systems; so these buildings have hot deck settings. Hot deck settings are one of the main factors affecting hot water consumption. Two buildings currently have the same hot deck settings implemented during CC, and the other three have different set points, which now call for more heating. The Blocker Building set points have been changed since the CC activity, as shown in Figure G, and demand more hot water during the entire year. The hot deck temperature settings for the summer may not cause higher consumption because many of the area maintenance operations staff will manually turn off the hot water valves in the summer.

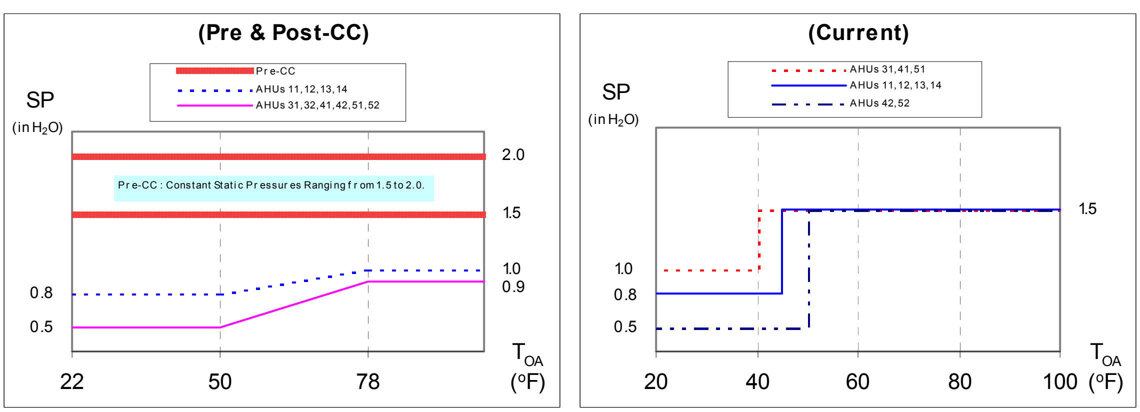


(a) (b)

Figure G: Comparison of pre-CC, post-CC, and current Hot Deck schedules in the Blocker Building pre-CC, post-CC.

Static Pressure Settings

Static pressure settings can affect not only CHW and HW consumption, but also electricity consumption.



(a) (b)

Figure H: Comparison of pre-CC, post-CC, and current Static Pressure schedules in the Blocker Building.

There are eight buildings equipped with Variable Air Volume (VAV) AHU systems. The Koldus Building has had the same settings since CC activity, but the others show that current settings demand more static pressure, which means cooling, heating, and electrical demands have been increased over time. Figure H(a) has the pre and post-CC settings for the Blocker Building, and Figure H(b) shows the current static pressure settings for the various air handlers.

Other Settings

Building differential pressure settings and control of outside air are also important CC measures to save energy and to maintain comfort. These control schemes generally have not been changed after CC. Some buildings also have economizer cycles to achieve comfortable conditions by using ambient air without refrigeration. The Harrington Tower, for example, uses two types of economizers, one temperature-controlled and one enthalpy-controlled. Changes in these parameters will impact the CC energy consumption, but these have not been investigated in detail for this paper.

Persistence Analysis

The 10 buildings investigated here were commissioned only and did not have any major retrofits other than controls upgrades. Table 2 summarizes the cost saving results for all 10 buildings. Energy cost savings were calculated by using the historic campus energy costs of $4.67/MMBtu for chilled water, $4.75/MMBtu for hot water, and $0.02788/KWh for electricity.

Cost savings for the first year of 10 buildings after CC were $1,126,000 and, based on this number, if we assume this reduction persisted, the calculated savings for four years after CC, (3 years for the Blocker building), would be $4,422,000. The averaged savings after CC, $4,255,000, were a little lower than that. As seen in Table 2, only two buildings, Kleberg and Wehner, have saved more money per year since the CC process than the first year right after CC. The savings of the other buildings have decreased.

Chilled water savings for all 10 buildings for the first year after CC came to an average of 44%, hot water savings 62%, and electric savings 12%. On the other hand, chilled water savings since CC activities averaged 40%, hot water savings averaged 62%, and electric savings averaged 11%. Hot water savings have maintained the same rate of savings during the last 4 years after CC process. These numbers above represent a successful result of persistence of savings obtained from Continuous Commissioning activities. These buildings have been followed-up after commissioning, recalibrating EMCS settings, troubleshooting some problems, and monitoring the energy use on a regular basis. Texas A&M University has been adding more students to the campus for the past several years, which could add additional occupant and plug-loads. This is one of the main factors increasing energy demand.

Table 2: Cost savings calculations for the first year and 4 year average after CC activity

No.	Buildings	Type	Baseline Energy Use	First Year(1997) after CC				4 yrs Avg. after CC
				Energy Use	Savings	Cost Savings		
					MMBtu/yr	Each $/yr	Total $/yr	Total $/yr
1	Blocker	CHW	21974	16924	5050	$ 23,583	$ 75,175	$ 68,515 *
		HW	8735	4093	4643	$ 22,054		
		Elec (KWh)	4832440	3772959	1059481	$ 29,538		
2	Eller O&M	CHW	30632	18946	11686	$ 54,573	$ 111,626	$108,346
		HW	7584	2578	5005	$ 23,776		
		Elec (KWh)	4891451	3697901	1193550	$ 33,276		
3	G.R.White Coliseum	CHW	18872	8717	10155	$ 47,422	$ 124,750	$115,570
		HW	21295	6091	15205	$ 72,222		
		Elec (KWh)	1480499	1297385	183114	$ 5,105		
4	Harrington Tower	CHW	14181	7104	7077	$ 33,049	$ 63,739	$ 57,054
		HW	6896	2603	4293	$ 20,394		
		Elec (KWh)	1666050	1296727	369323	$ 10,297		
5	Kleberg Building	CHW	59271	34864	24407	$ 113,979	$ 278,303	$279,930
		HW	40812	6523	34289	$ 162,871		
		Elec (KWh)	5510592	5458473	52119	$ 1,453		
6	Koldus Building	CHW	19265	12182	7083	$ 33,076	$ 49,519	$ 48,823
		HW	2176	704	1472	$ 6,993		
		Elec (KWh)	2850190	2511244	338946	$ 9,450		
7	Richardson Petroleum	CHW	28526	13599	14927	$ 69,707	$ 121,576	$118,250
		HW	17277	6565	10712	$ 50,884		
		Elec(KWh)	1933040	1897734	35306	$ 984		
8	VMC Addition	CHW	40892	23115	17777	$ 83,017	$ 101,059	$ 92,649
		HW	3569	887	2682	$ 12,739		
		Elec(KWh)	4185825	3995579	190245	$ 5,304		
9	Wehner CBA	CHW	19193	12327	6865	$ 32,061	$ 48,038	$ 56,889
		HW	13393	10876	2517	$ 11,956		
		Elec(KWh)	2554720	2410493	144227	$ 4,021		
10	Zachry Engr Center	CHW	40830	16714	24116	$ 112,622	$ 146,494	$130,730
		HW	4415	1630	2785	$ 13,229		
		Elec(KWh)	7502371	6761957	740414	$ 20,643		

* This cost saving is based on 3 years average after CC

Conclusions & Recommendations

Continuous Commissioning consists of a large number of tasks that take substantial time and effort to maintain building mechanical and control equipment. This investigation of the persistence of savings obtained from Continuous Commissioning found that the savings have slowly degraded over the years, but are still saving large amounts of money and energy annually. Results of the 10 buildings on the Texas A&M University campus at College Station showed cumulative savings of $4,255,000 during the last four years after CC. The results from this study demonstrates to the building owners (Texas A&M) that their commissioning investment has not significantly degraded over time, but it does indicate that CC settings should be verified periodically.

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California Energy Commission
Public Interest Energy Research Program

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HPCBS

High Performance Commercial Building Systems

Is Commissioning Once Enough?

Element 5. Integrated Commissioning and Diagnostics
Project 2.2 - Monitoring and Commissioning of Existing Buildings
Task 2.2.5 - Investigate the persistence of the benefits obtained from different types of commissioning and continuous commissionings

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IS COMMISSIONING ONCE ENOUGH?

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ABSTRACT

The Energy Systems Laboratory has developed a commissioning process called Continuous Commissioning[SM] over the last decade. This process is used to resolve operating problems, improve comfort, optimize energy use, and sometimes to recommend retrofits. The process has produced average energy savings of about 20% without significant capital investment in well over 100 large buildings in which it has been implemented. Payback has virtually always been under 3 years with most at two years or less.

This paper describes the process and presents recent evidence of the need for follow-up commissioning when indicated by consumption increases. A case study is presented that specifically shows the value of this follow-up.

INTRODUCTION TO CONTINUOUS COMMISSIONING[SM]

Continuous Commissioning (CC[SM]) started at the Energy Systems Laboratory (ESL) of Texas A&M University as an attempt to achieve energy and cost savings with operations and maintenance (O&M) procedures (Liu et al. 1994). It evolved into a commissioning process that is a way of problem solving in buildings, which helps problems stay fixed longer than conventional trouble-shooting procedures and simultaneously helps reduce energy costs (Liu et al. 1999). It requires knowledge of the fundamentals of humidity, airflow, water flow, and heat flow. This knowledge must be combined with a practical and fundamental knowledge of building systems and building operation to diagnose the cause(s) of problems (Liu et al. 1996). These elements are then combined to solve the problems. Use of this approach typically not only makes problems stay fixed longer; it makes a building operate more efficiently and hence at lower cost. This process attempts to optimize building operation for current requirements. It has primarily been applied to existing buildings, and in that respect resembles what has come to be called retro commissioning. However, it has also been applied to new buildings where it differs from conventional new building commissioning with its emphasis on performance optimization. On-going monitoring of energy consumption with commissioning follow-up as needed has been recommended as an integral part of the process since the mid-1990s.

To date CC has been applied to well over one hundred large buildings with a total floor area of well over 10 million square feet and has reduced energy costs by an average of 20% without appreciable capital investment. Gregerson (1997) investigated existing building commissioning in 1997 and reported average savings of 11.8% for 13 buildings which had undergone conventional commissioning. The average savings noted for the 21 buildings that had undergone CC was 23.8%.

Buildings that have had retrofits and buildings that have not had recent upgrades to the HVAC equipment comprise two significantly different categories to which the CC process has been applied. The average savings due to the process in buildings that had already been retrofit were about 20% beyond the retrofit savings (Claridge et al. 1996). A more recent paper (Claridge et al. 2000) reported that application of the CC process to buildings that had not generally been retrofit produced savings averaging 28% for cooling, 54% for heating, and savings of 2 to 20% for other electrical uses.

THE CONTINUOUS COMMISSIONING PROCESS

The Continuous Commissioning Process is shown schematically in Figure 1 as outlined in Claridge et al (2000).

The first step in the CC process is to perform an initial survey of the building and discover the comfort and operational problems that are present. During this survey,

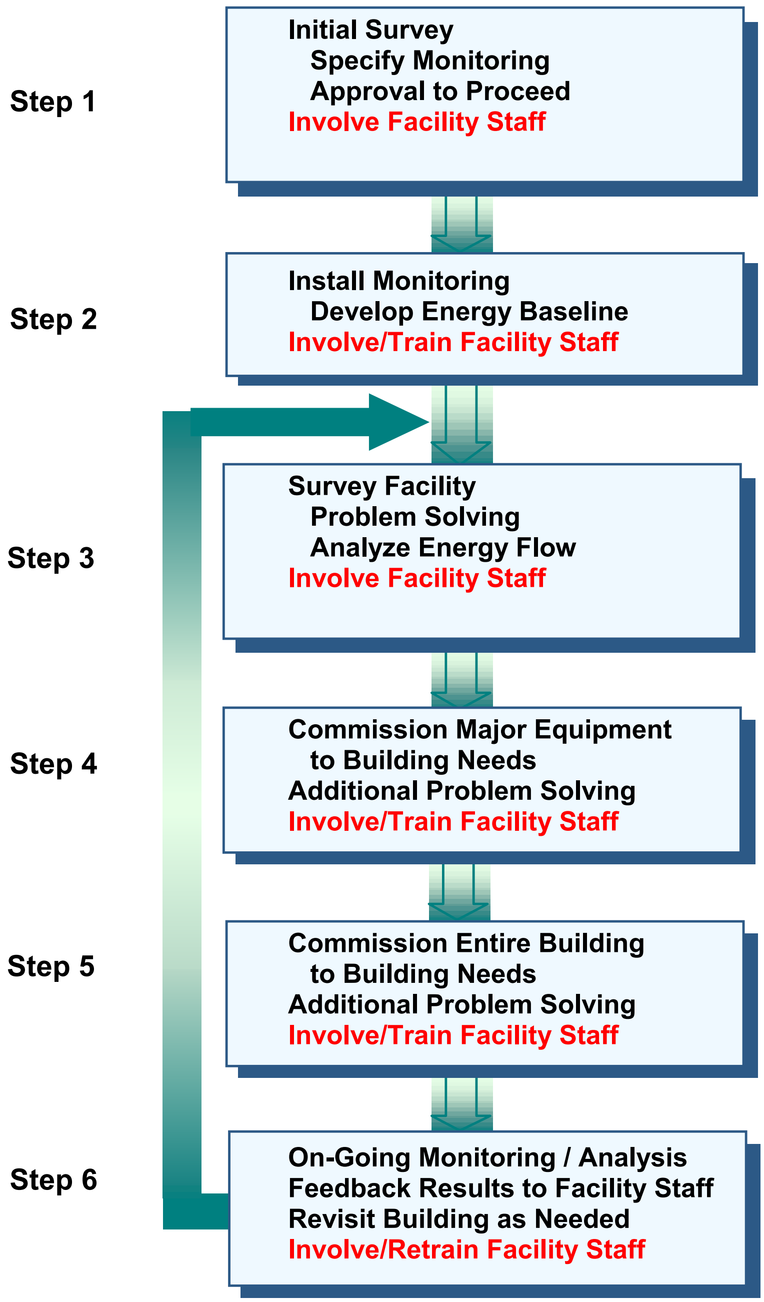

FIGURE 1. THE CONTINUOUS COMMISSIONING PROCESS

an initial estimate of the potential CC savings and an estimate of the monitoring requirements are made. One of the fundamental requirements for CC to be effective is to involve the facility staff in each of the steps so that they will understand and support the planned enhancements to the operations and the facility. Training in Step 1 is usually informal and generally involves discussions as the CC engineer surveys the facility.

A method for measuring and modeling the baseline performance of the facility must be established to determine the impact of the CC process. Equipment is normally installed to separately monitor at least heating, cooling, and other electric consumption on at least an hourly basis and a baseline started in Step 2. This equipment may be installed and owned by the utility or may be owned by the facility. If the metering will be maintained by the building staff, they need to be involved in the installation and should be given installation responsibility if possible. This creates ownership and will allow a much faster repair of sensors when needed. The training in Step 2 is informal and should involve hands-on participation in the installation process.

The CC engineer next performs a detailed facility survey in Step 3. This survey utilizes data from the energy monitoring equipment, the control system, and numerous one-time measurements of temperatures, pressures, and flows made throughout the building. Any broken components or any causes of discomfort are identified and fixed. Also, a team must be formed between the CC engineers and the facility staff. Getting the building back up to proper function is very important as this provides an immediate benefit to the occupants. Having the facility person involved with this step helps to minimize actions by operators to "undo" changes implemented as part of the repair process if complaints occur. Before proceeding, the facility environment should be comfortable and the equipment should be operating acceptably. For example, if the airflow through air handler 5 is increased to improve the temperature in the Dean's Office, discomfort may be created in the EE Department Head's office, two doors down. The CC team identifies these problems, develops a plan for solving them and then solves them. The CC engineers work with the facility staff until solutions are identified and in place. The CC engineer must have an excellent fundamental understanding of the systems in the building combined with substantial practical experience with these systems.

Commissioning the equipment to the facility needs and then commissioning the entire facility to the facility needs are completed in Steps 4 and 5. Commissioning to facility needs involves problem analysis and solution. When equipment is oversized, a typical finding, the operation is usually non-optimal. The CC engineer must understand the operation of the equipment in the equipment room and also how energy is transported in the facility.

Monitoring, in Step 6, is key to measuring the changes and being able to report the savings obtained. Monitoring also serves as an early warning if changes were made in the facility which degrade the operation or savings. A CC engineer needs to visit to facility to review the operation whenever the building consumption increases significantly. Often facility staff change and retraining is important. Also, facility use often changes and these visits will be useful for identifying additional needs at the site. The CC process optimizes the building as it was being operated. For example, if one-half of a floor of offices was converted to labs, it is very likely the energy use of the space will have changed and will need to be optimized. Additional information on the CC process is provided in Liu et al. (1994, 1999) and in Claridge et al. (2000)

CASES WHERE CONTINUOUS COMMISSIONING MAY BE USED

The CC process has been applied almost exclusively to buildings with a floor area of at least 5,000 m^2. About 90% of the buildings to which the process has been applied are in cooling dominated climates where typical cooling consumption in large buildings is at least two times the heating consumption. However, it has also been successfully applied to buildings in the coldest parts of the continental United States. It is a relatively labor intense process at this time, making it generally more applicable to buildings with large air handlers and large total energy use. Automated control systems tend to simplify implementation of CC and it has been particularly effective in buildings that exhibit significant simultaneous heating and cooling. If the CC process were to be implemented in all in the commercial buildings larger than 50,000 ft^2 in the United States, and achieve comparable savings, it would have the potential to reduce consumption in the commercial buildings sector by 8%. Of course, if it were successfully implemented on that scale, it can be anticipated that a variety of automated techniques would make it applicable to smaller buildings and expand the potential impact.

CASE STUDY - KLEBERG BUILDING

The Kleberg Building is a teaching/research facility on the Texas A&M campus consisting of classrooms, offices and laboratories, with a total floor area of approximately 165,030 ft^2. Ninety percent of the building is heated and cooled by two (2) single duct variable air volume (VAV) air handling units (AHU) each having a pre-heat coil, a cooling coil, one supply air fan (100 hp), and a return air fan (25 hp). Two smaller constant volume units handle the teaching/lecture rooms in the building. The campus plant provides chilled water and hot water to the building. The two (2) parallel chilled water pumps (2×20 hp) have variable frequency drive control. There are 120 fan-powered VAV boxes with terminal reheat in 12 laboratory zones and 100 fan-powered VAV boxes with terminal reheat in the offices. There are six (6) exhaust fans (10-20 hp, total 90 hp) for fume hoods and laboratory general exhaust. The air handling units, chilled water pumps and 12 laboratory zones are controlled by a direct digital control (DDC) system. DDC controllers modulate dampers to control exhaust airflow from fume hoods and laboratory general exhaust.

A CC investigation was initiated in the summer of 1996 due to the extremely high level of simultaneous heating and cooling observed in the building (Abbas, 1996). Figures 2 and 3 show daily heating and cooling consumption (expressed in average kBtu/hr) as functions of daily average temperature. The Pre-CC data heating given in Figure 2 shows very little temperature dependence as indicted by the regression line derived from the data. Data values were typically between 5 and 6 MMBtu/hr with occasional lower values. The cooling data (Figure 3) shows more temperature dependence and the regression line indicates that average consumption on a design day would exceed 10 MMBtu/hr. This corresponds to only 198 sq.ft./ ton based on average load.

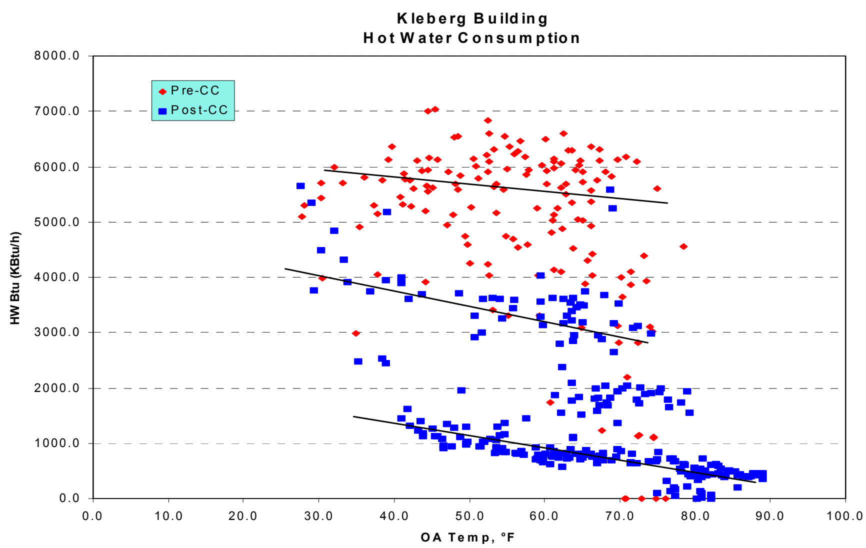

FIGURE 2. PRE-CC AND POST-CC HEATING WATER CONSUMPTION AT THE KLEBERG BUILDING VS DAILY AVERAGE OUTDOOR TEMPERATURE.

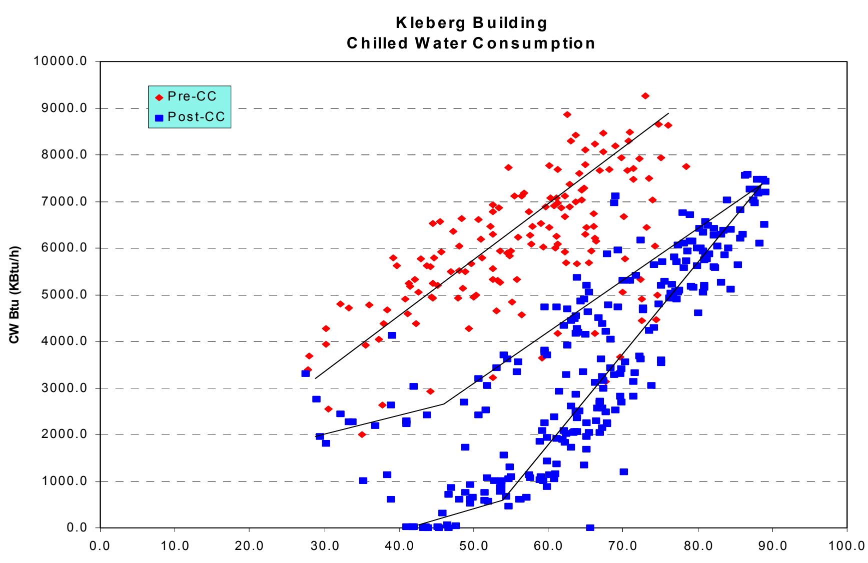

FIGURE 3. PRE-CC AND POST-CC CHILLED WATER CONSUMPTION AT THE KLEBERG BUILDING VS. DAILY AVERAGE OUTDOOR TEMPERATURE.

It was soon found that the preheat was operating continuously, heating the mixed air entering the cooling coil to approximately 105˚F, instituted in response to a humidity problem in the building. The preheat was turned off and heating and cooling consumption both dropped by about 2 MMBtu/hour as shown by the middle clouds of data in Figures 2 and 3. Subsequently, the building was thoroughly examined and a comprehensive list of commissioning measures was developed and implemented. The principal measures implemented that led to reduced heating and cooling consumption were:

- Preheat to 105˚F was changed to preheat to 40˚F
- Cold deck schedule changed from 55˚F fixed to vary from 62˚F to 57˚F as ambient varies from 40˚F to 60˚F
- Economizer – set to maintain mixed air at 57˚F whenever outside air below 60˚F
- Static pressure control – reduced from 1.5 inH2O to 1.0 inH2O and implemented night-time set back to 0.5 inH2O
- Replaced or repaired a number of broken VFD boxes
- Chilled water pump VFDs were turned on.

Additional measures implemented included changes in CHW pump control – changed so one pump modulates to full speed before second pump comes on instead of operating both pumps in parallel at all times, building static pressure was reduced from 0.05 inH2O to 0.02 inH2O, and control changes were made to eliminate hunting in several valves. It was also observed that there was a vibration at a particular frequency in the pump VFDs that influenced the operators to place these VFDs in the manual mode, so it was recommended that the mountings be modified to solve this problem.

These changes further reduced chilled water and heating hot water use as shown in Figures 2 and 3 for a total annualized reduction of 63% in chilled water use and 84% in hot water use. Additional follow-up conducted from June 1998 through April 1999 focused on air balance in the 12 laboratory zones, general exhaust system rescheduling, VAV terminal box calibration, adjusting the actuators and dampers, and calibrating fume hoods and return bypass devices to remote DDC control (Lewis, et al. 1999). These changes reduced electricity consumption by about 7% or 30,000 kWh/mo.

In 2001 it was observed that chilled water savings for 2000 had declined to 38% and hot water savings to 62% as shown in Table 1. Chilled water data for 2001 and the first three months of 2002 are shown in Figure 4. The two lines shown are the regression fits to the chilled water data before CC implementation and after implementation of CC measures in 1996 as shown in Figure 3. It is evident that consumption during 2001 is generally appreciably higher than immediately following implementation of CC measures. The CC group performed field tests and analyses that soon focused on two SDVAV AHU systems, two chilled water pumps, and the Energy Management Control System (EMCS) control algorithms as described in Chen et al. (2002). Several problems were observed as noted below.

TABLE 1. CHILLED WATER AND HEATING WATER USAGE AND SAVING IN THE KLEBERG BUILDING FOR THREE DIFFERENT YEARS NORMALIZED TO 1995 WEATHER.

Type	Pre-CC Baseline (MMBtu/yr)	Post-CC Use/Savings		2000 Use/Savings	
		Use (MMBtu/yr)	Savings (%)	Use (MMBtu/yr)	Savings (%)
CHW	72935	26537	63.6%	45431	37.7%
HW	43296	6841	84.2%	16351	62.2%

Problems Identified

- The majority of the VFDs were running at a constant speed near 100% speed.
- VFD control on two chilled water pumps was again by passed to run at full speed.
- Two chilled water control valves were leaking badly. Combined with a failed electronic to pneumatic switch and the high water pressure noted above, this resulted in discharge air temperatures of 50F and lower and activated preheat continuously.
- A failed pressure sensor and two failed CO2 sensors put all outside air dampers to the full open position.
- The damper actuators were leaking and unable to maintain pressure in some of the VAV boxes. This caused cold air to flow through the boxes even when they were in the heating mode, resulting in simultaneous heating and cooling. Furthermore some of the reheat valves were malfunctioning. This caused the reheat to remain on continuously in some cases.
- Additional problems identified from the field survey included the following: 1) high air resistance from the filters and coils, 2) errors in a temperature

sensor and static pressure sensor, 3) high static pressure set points in AHU1&AHU2.

A combination of equipment failure compounded by control changes that returned several pumps and fans to constant speed operation had the consequence of increasing chilled water use by 18,894 MMBtu and hot water use by 9,510 MMBtu. This amounted to an increase of 71% in chilled water use and more than doubled hot water use from two years earlier

These problems have now been largely corrected and building performance has returned to previously low levels as illustrated by the data for April-June 2002 in Figure 4. This data is all below the lower of the two regression lines and is comparable to the level achieved after additional CC measures were implemented in 1998-99.

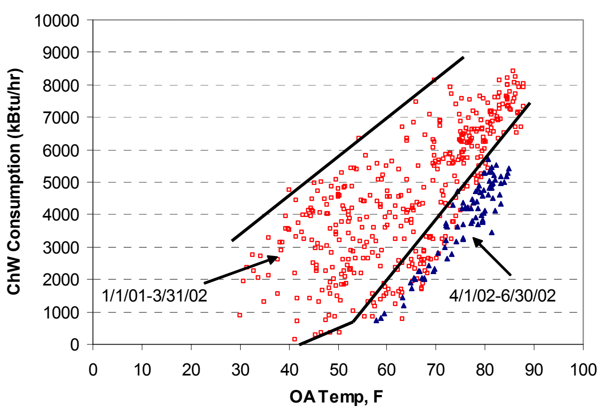

FIGURE 4. CHW DATA FOR THE KLEBERG BUILDING SINCE JANUARY 2001.

WHEN IS FOLLOW-UP COMMISSIONING NEEDED?

For the Kleberg Building, it is clear that a combination of control changes and component problems led to a need for follow-up commissioning measures. In principle, these measures could be viewed as routine maintenance, but since they had not led to comfort problems, it is unlikely that they would have been addressed unless they ultimately resulted in a comfort problem. Even then without the evidence of the $66,500/year increase in consumption, it is unlikely that a comprehensive follow-up effort would have occurred. But how often do such problems occur?

The ESL has conducted a study of 10 buildings on the A&M campus that had CC measures implemented in 1996-97. Table 2 shows the baseline cost of combined heating, cooling and electricity use of each building and the commissioning savings for 1998 and 2000. The baseline consumption and savings for each year were normalized to remove any differences due to weather (see Turner, et al. 2001 for details).

Looking at the totals for the group of 10 buildings, savings decreased by over $207,258 (17%) from 1998 to 2000, but were still very substantial. However, it may also be observed that almost ¾ of this decrease occurred in two buildings, the Kleberg Building, and G. Rollie White Coliseum. The increased consumption of the Kleberg Building was due to a combination of component failures and control problems as already discussed. The increased consumption in G. Rollie White Coliseum was due

TABLE 2. COMMISSIONING SAVINGS IN 1998 AND 2000 FOR 10 BUILDINGS ON THE TEXAS A&M CAMPUS.

Building	Baseline Use ($/yr)	1998 Savings ($/yr)	2000 Savings($/yr)
Kleberg Building	$ 484,899	$ 313,958	$ 247,415
G.R. White Coliseum	$ 229,881	$ 154,973	$ 71,809
Blocker Building	$ 283,407	$ 76,003	$ 56,738
Eller O&M Building	$ 315,404	$ 120,339	$ 89,934
Harrington Tower	$ 145,420	$ 64,498	$ 48,816
Koldus Building	$ 192,019	$ 57,076	$ 61,540
Richardson Petroleum Building	$ 273,687	$ 120,745	$120,666
Veterinary Medical Center Addition	$ 324,624	$ 87,059	$ 92,942
Wehner Business Building	$ 224,481	$ 47,834	$ 68,145
Zachry Engineering Center	$ 436,265	$ 150,400	$127,620
Totals	$ 2,910,087	$ 1,192,884	$ 985,626

to different specific failures and changes, but was qualitatively similar to Kleberg since it resulted from a combination of component failures and control changes. The five buildings that showed consumption increases above 5% from 1998 to 2000 were all found to have different control settings that appear to account for the changed consumption (including the decrease in the Wehner Business Building).

This data does not explicitly answer the question "When is follow-up commissioning needed?", but the authors believe it suggests that tracking consumption and investigating the reasons for significant increases is likely to provide real benefits.

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